Z. E. SLOAN

SATURN SYSTEMS AUTOMATION

PRELIMINARY STUDY REPORT FOR

MARSHALL SPACE FLIGHT

CENTER

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VOLUME I TECHNICAL REPORT

SPACE TECHNOLOGY LABORATORIES, INC.
A SUBSIDIARY OF THOMPSON RAMO WOOLDRIDGE INC.
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

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Volume I
Technical Report

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Computer Control, Launch Control, and Propellant Loading Consoles

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1. INTRODUCTION

This report presents the results of a preliminary study on development of an automation system for checkout and launch of the Saturn C-1 and C-5 vehicles. The study was undertaken on an unfunded basis because it promised further to enhance STL's capability in the area of automatic checkout equipment for booster and space vehicles, and also because it provided an opportunity to work with MSFC personnel and to present a number of independent ideas about automating the Saturn system. It is hoped that this initial contribution will be of help to MSFC and will serve to demonstrate a capability to render further assistance with the Saturn automation work.

The general approach taken during the study was first to develop a preliminary system configuration for the automated launch complexes and then to perform more detailed design work on equipment areas of major interest and importance. This report therefore represents a collation of preliminary design studies rather than a complete and comprehensive specification for the automation system. Now that the initial study has been concluded, work can logically advance to development of detailed specifications for the C-1 and C-5 automation systems.

During the studies, little time was spent on development of detailed requirements for the general-purpose digital computer. The assumption was made that MSFC had examined the problem carefully and that the RCA-110 computer had been selected for this application. Consequently, the automation system developed during the study was tailored to the computation and input/output characteristics of the RCA-110 unit.

On the other hand, major emphasis was placed on those equipment areas concerned with processing of test data, control of test operation, display of test status and results, development of test programs, and automation of mechanical test operations. In the area of computer control and data display, the preliminary work was quite extensive and a large amount of detail is presented in this report. In some other areas, preliminary design was generalized because of the lack of detailed knowledge about the Saturn vehicle, telemetry system, and existing

C-1 vehicle ground equipment. However, initial trade-off studies were either completed or identified in all areas, and where specific knowledge about the Saturn vehicle was lacking, preliminary design work was based on a background of experience with other vehicles having similar functional requirements for checkout and launch.

This study was particularly interesting to STL because it represented a logical extension of much previous work. For several years, STL has been actively engaged in development of automatic checkout and launch equipment for booster and space vehicles. For example, recent effort closely related to the Saturn automation plan involved preliminary design of an automation system for the Apollo spacecraft. This work consisted of several months of intensive effort during the fall of 1961 and was performed as part of the General Electric team proposal to NASA for development of the spacecraft and related ground systems. The automation system proposed was strikingly similar to the MSFC concept for automation of the Saturn vehicle, making use of a central, general purpose computer for test control and data evaluation. Many of the detailed trade-off studies and much of the system work for Apollo turn out to be directly applicable to the Saturn automation study.

In addition to the Apollo work STL has conducted other related programs for automation of test and launch operations. The OGO spacecraft program is a good example where STL has been responsible not only for system design but also for development of the automation equipment, in which digital techniques and equipment are used throughout. Other important examples of relevant experience are the Minuteman, Titan, and Atlas missile programs. For these systems, STL was responsible for system design and technical integration of completely automated operational checkout and launch equipments. This background of experience constitutes a resource that is available to MSFC for assistance with the Saturn systems automation activity.

With this background in mind, the present study was initiated with the following major objectives:

a) To develop the requirements and an initial system configuration for automation of the Saturn C-1 and C-5 launch complexes.

b) To identify major system areas where future trade-off studies would be required.

c) To suggest a plan whereby STL could assist MSFC with the automation work.

To assist with detailed planning of the study effort, information was requested and obtained from MSFC regarding their general automation concept and plans for incorporation of such a system in the C-1 and C-5 launch complexes at AMR. The study was then conducted on the basis of these inputs with results presented in later sections of this report.

During the preparation of this report, STL felt it would be useful to include relevant background information obtained from various published documents and from conversations with MSFC personnel. The material is presented to document the MSFC concept as understood by STL and to assist the reader in understanding later sections of the report. Sections 2 through 4 are therefore devoted to an account of this background under the following subject headings:

2. GENERAL TEST PHILOSOPHY

3. GENERAL BACKGROUND INFORMATION

4. STAGE GROUND SUPPORT EQUIPMENT

The section on General Test Philosophy describes the requirement for automation and discusses other important test concepts to be implemented for the Saturn program. The section entitled General Background Information summarizes MSFC plans for development both of stage and vehicle ground support equipment. It describes the complementary functions of the two types of equipment and indicates the general test concept to be implemented from factory to launch. It also outlines the plan for gradual phase-in of the vehicle checkout and launch automation equipment on C-1 flights starting with SA-5. The section on Stage Ground Support Equipment is essentially a summary description of that type of equipment as interpreted from various reports and discussions with MSFC personnel.

The remaining sections of the report contain essentially new material developed during the course of the study. Section 5 treats the development of an automation system for the C-1 vehicle. The design is based on a general concept developed by MSFC, with emphasis placed on further definition of the hardware requirements. The approach taken was to develop a rather complete equipment configuration for automating the C-1 launch complex and then to detail the functional requirements for each unit of equipment. Particular attention was given to developing and describing the control and display capabilities available to the test operators.

Section 6 presents a detailed description of an automation system for checkout and launch of the C-5 vehicle. Again, the approach taken was to develop an initial equipment configuration and then perform a preliminary design study for each major unit of automation equipment. Wherever possible, the objective was to use the same equipment for early automation of the C-1 complex as would be later required for the C-5 system.

Section 7 outlines the general operations concept recommended for effective use of the automation system. Included in this section are such items as test sequence programming, program loading and verification, self-verification of the automation system, and a description of the guidance system and its relation to the automatic checkout equipment. Whereas the two previous sections were concerned with a detailed description of automation equipment, this section is largely concerned with operation and use of the equipment.

Section 8 consists of a discussion of automation techniques for mechanical test and launch operations. Recent discussions with MSFC have indicated a particular need for detailed work in this area. During the study, a special effort was made to identify important test areas for detailed study, such as pressure sensing, leak detection, and propellant loading. A certain amount of generalization was found necessary because of a lack of specific knowledge about vehicle and engine characteristics. Nevertheless, this initial work is directly applicable to the Saturn program and provides a basis for continued effort. The results show that most mechanical test operations can and should be automated.

It appears that one important consideration will be adequate provisioning of signal transducers both in the vehicle and ground equipment to properly facilitate the test operations. Further study is needed to define the requirements in this area.

Section 9 contains a discussion of those special areas in which future trade-off studies are required. Included under this category are such topics as development of a common digital language for the automation system, integration of Apollo GSE, optimum utilization of telemetry data, data link requirements for Complex 39, etc. Some initial thought has been given to each of these areas as part of this preliminary study in order that the scope of future work might be planned and described.

Appendix A is included for related background information. It is a summary description of the Saturn vehicle and has been used as the basis for design of the automation system.

2. GENERAL TEST PHILOSOPHY

A fundamental objective of the test program and related ground support equipment for the Saturn system is to maximize the probability of mission success. A further goal is to guarantee crew safety on manned missions. To meet these ends, a test program has been carefully planned for each vehicle stage, from factory acceptance through launch. An optimum set of test and launch equipment will be provided under the direction of MSFC to implement this plan.

Several important concepts will govern development of test equipment for the Saturn system:

a) Test operations will be automated both for checkout and launch of the assembled vehicle and for checkout of the individual stages.

b) Standardized test procedures and equipment will be utilized for an individual stage of equipment as it progresses from factory acceptance through launch.

c) Flight systems will be specifically designed for testability by the automatic checkout equipment.

d) Telemetry data will be used extensively for checkout of individual stages of equipment and the assembled vehicle.

e) Automation equipment will be designed for use by trained engineering personnel.

f) Automation techniques and hardware will be selected for universal application to succeeding vehicle configurations.

There are several important reasons for automating the Saturn test operation. First, launch schedules are far too crowded for conventional manual checkout and launch procedures. Automation of these operations appears to be the only practical way to save time and make the most efficient use of available and experienced personnel. Another important consideration is the improvement in overall vehicle reliability to be gained by standardizing test operations, reducing test time on the flight hardware, and eliminating human error. When an equipment malfunction has been noted, the exact condition under which that failure occurred is known and can be readily duplicated.

When designed properly, automatic checkout equipment provides an additional advantage of facilitating data gathering and recording for separate evaluation of performance history and testing trends. This capability is particularly important for the Saturn vehicle because of the high reliability requirements and the extremely large amount of test data. To further facilitate the systematic evaluation of performance history, the requirement listed above under item (b) has also been imposed. Use of common test procedures and equipment from factory acceptance through launch will ensure compatibility of data obtained at each site and thus will greatly enhance the program for systematic evaluation of performance history.

Although the exact nature of the ground support equipment for the Saturn program will vary from stage to stage and from one test location to another, a basic goal is to provide a standard set of test procedures and equipment capable of performing all phases of the carefully planned test program. Standardized equipment will be introduced as far upstream in the manufacturing flow as possible and in all cases will be used for stage testing from final acceptance through launch. Although the exact data and planned usage will vary as the program progresses, every attempt will be made to perform certain measurements at every test opportunity, thereby providing a continuum of test data for comparison purposes. Liftoff is considered to be merely the mid-point of any given mission, and in many instances a backlog of test data taken before launch is a prerequisite to the successful completion of the mission.

Another item of test philosophy is the requirement for design of flight systems to be testable by the automatic checkout equipment. Lack of proper attention to this aspect can greatly reduce the inherent capability of the automatic checkout approach and lead to an inferior or even inadequate test operation. Items of general importance in this area are provisioning of the necessary test points and signal transducers to properly evaluate performance and to isolate malfunctions. One item of particular importance for this application is provisioning of test points with low impedance outputs for operation over relatively long lines at the launch complex. Another item frequently neglected on other vehicle programs is adequate provisioning of signal transducers to facilitate mechanical test operations. These and related items must be considered to take full advantage of the inherently high test capability offered by the automatic checkout equipment.

The requirement for extensive use of telemetry data during checkout of individual stages of equipment and the assembled vehicle is facilitated by digital telemetry. This type of telemetry provides data in a form easily adaptable to automatic evaluation. Important advantages of this approach are the minimizing of hardline connections through an umbilical and standardization of test data before and after launch.

As indicated, the automatic system will be designed for use by trained engineering personnel. Because only two or three systems will be produced, economic considerations make it practical to use high-level engineering personnel for operation of the computer complex and associated equipment. To make best use of this grade of personnel, the automation system will be designed for maximum operator participation during both normal and troubleshooting operations.

Selection of automation techniques and hardware will be based on universal application to all vehicles in the Saturn-Nova series. The development work must consider all GSE requirements for these vehicles, including incorporation of a nuclear-powered upper stage (RIFT). The same GSE technologies and the same hardware, wherever possible, will be used throughout the Saturn-Nova development cycle, just as vehicle technologies are being utilized from one vehicle configuration to another.

3. GENERAL BACKGROUND INFORMATION

This section contains general background information obtained from various published sources and from discussions with MSFC personnel. The material is presented to document the MSFC test concept for Saturn as understood by STL and to assist the reader in understanding later sections of the report.

3.1 Test Locations

Recent discussions with MSFC have provided an indication of the test plan to be followed for the various Saturn stages and the assembled vehicle. The major test areas to be facilitated with ground support equipment are as follows:

a) Factory

b) Static firing site

c) Staging building at AMR

d) Vehicle assembly area at AMR

e) Launch pad.

The first three of these test areas are for individual stages and will make use of test equipment provided by stage contractors. The latter two test areas are for the assembled vehicle and will make use of separate sets of automated test and launch equipment to be provisioned through MSFC. The present concept for the overall test program requires that each stage be tested at the factory, at the static site, and then at the staging building at AMR, utilizing test equipment as designed for that particular stage. It is anticipated that the GSE for stage check-out will take the form of a general-purpose digital computer, a set of buffering, control, and display equipment, and a rather simple signal distribution box. Of this equipment, only the signal distribution box (or an electrically equivalent unit) would also be used as part of the automated checkout and launch equipment for the assembled vehicle.

The stages will be assembled together and checked out as a vehicle for the first time in the assembly area at AMR. It is anticipated that the checkout equipment to be utilized at the assembly area and launch pad will utilize an RCA-110 computer, telemetry ground station, signal distributors for each stage, and a set of buffering, control, and display equipment.

The assembly and launch areas are quite different for the C-1 and C-4 vehicles. In the case of the C-1, the vehicle is assembled directly on the launch pad. Complexes 34 and 37 for the C-1 have a blockhouse approximately 1700 feet from the launching pad which serves as a test and launch control center in the conventional manner.

A special assembly building is provided for the C-5 vehicle. Upper stages, including the spacecraft, are first brought to the stage checkout area where they are qualified as individual stages. The stages are then assembled into total vehicles in a vertical fashion on transporters in a vertical assembly area. Each transporter has its own set of GSE which is capable of a complete and independent operational checkout of the vehicle system. At about one week prior to launch, a transporter with its checked-out vehicle and GSE system will be moved along a rail system to take its firing position on one of two launching pads. Along the way it will receive ordnance installation, high pressure checks, etc. Upon reaching the pad, the vehicle system will be connected to propellant loading facilities similar in nature to those used in operation of Complex 37. Checkout of the vehicle system can continue just as it did in the vertical assembly facility, since the transporter and its GSE are capable of independent operation.

At a time when the entire launch operation is to be simulated, such as Simulated Flight Test, the transporter GSE is tied through a communications link to an operational computer located in the vertical assembly facility. All operations of the vehicle system can now be handled remotely through this data link. On launch day the transporter GSE and vehicle system would continue to operate under program control of the operational computer with an operational flight control facility providing overall control and monitoring of the launch operation.

3.2 Test Data

The overall test program for the Saturn system will generate an extremely large amount of test data. Repeated test measurements will be made as each stage progresses through successive test areas from factory to launch. To facilitate effective use of the data, systematic methods of data processing will be developed to evaluate performance history and testing trends. Test procedures and equipment will be standardized as much as possible to provide maximum correlation among data obtained from different sites.

The types of data to be used for direct performance evaluation at the various test sites and also recorded for later systematic evaluation can be separated into the following general categories:

a) Operational measurements

b) Telemetry measurements.

The first category represents the test data which is necessary for evaluation of operational performance and which will be obtained primarily through hardline connections to the vehicle. The second category consists of data which are obtained through the telemetry r-f links and which will be available for evaluation of vehicle performance after launch. During stage checkout, the two categories will have considerable overlap so that the same operational measurements can be made through both the hardline connections and the telemetry link. For final vehicle checkout, the ultimate objective is to make use of the telemetry link as much as possible for operational measurement while minimizing the dependence on hardline connections. The attainment of this objective will be a gradual process depending upon the growth of experience, hardware reliability, and user confidence.

The general usage of test data to be made available at the various test locations can be categorized as follows:

3.2.1 Engineering Evaluation

Engineering evaluation of design at the stage level will be accomplished for the most part by use of operational and telemetry measurements. Additional instrumentation of a special nature will be used for certain developmental tests.

3.2.2 Acceptance Tests

Acceptance tests are performed as part of the final "buy off" of a stage at the factory wherein performance is checked against applicable specifications. Both operational and telemetry measurements are used for this function which serves to provide reference data against which all subsequent tests can be compared.

3.2.3 Prelaunch Reliability Assurance

Prelaunch reliability assurance is obtained by use of operational and telemetry measurements at AMR to establish the confidence required in committing a vehicle to the firing sequence. This assurance is obtained during stage checkout and vehicle assembly, the electrical sequencing after ordnance installation, and the final checkout during countdown.

3.2.4 Preventive Maintenance

One of the most important uses of test data as measured by its contribution to mission success probability is that which permits operating personnel to defeat the consequences of inevitable malfunction. Preventive maintenance is facilitated by systematic evaluation of the operational and telemetry data to detect drifts, trends, and marginal conditions. In this manner, incipient failure can be detected and avoided by component replacement, thereby improving reliability.

3.2.5 Malfunction Isolation

A primary function of the computer complex is to isolate malfunctions to the smallest removable module by logical evaluation of data obtained from the operational and telemetry measurements. As the Saturn program progresses, it is anticipated that the computer complex will play an increasingly larger role in such troubleshooting operations.

3.3 Incorporation of Automation

Automation of the Saturn vehicle test and launch operations at AMR will be phased-in gradually to facilitate an orderly system evaluation and to develop user confidence. An ultimate objective is to design an automation system for the C-5 vehicle while making use of the same techniques and equipment for early checkout with the C-1 system. Units of automation equipment will be used for the first time in Complex 37 beginning with launch preparation of Saturn SA-5. For the next five flights, the automation system will be used in conjunction with the existing manual equipment on an either/or basis, i.e., either an automatic or manual mode of operation can be utilized. In this capacity the automation system will monitor all operations and, at the discretion of the test conductor, will perform some or all of the operations for checkout and launch of the vehicle.

During this initial phase, personnel of LOD will become familiar with the automation system operation by monitoring automated test results while using the analog display capability provided by existing manual equipment. If desired, the manual consoles can be operated to duplicate and check any sequence of operations performed by the automation system. This capability for manual operation serves as a backup to the eventual automatic mode, and can be used in Complex 37 until automation equipment reliability and operator confidence allow complete use of the system for checkout and launch. Present expectations are that the Saturn C-1, SA-111 will be launched from Complex 37 in a fully automatic manner. Test operations at Complex 39 will be automated to the maximum extent possible, starting with launch of the first C-5 vehicle.

The degree to which the above automation schedule can be implemented is based on the availability of compatible stage equipment and stage interface GSE. It now appears that some test operations for the S-IV stage of the C-1 vehicle will, of necessity, be performed manually until change to the S-IVB configuration. Similarly, it appears that the S-II stage of the C-5 vehicle will be checked out manually for the first few units. On the other hand, both the S-I and instrumentation stages of the C-1 vehicle should be compatible with the automation system starting with Saturn SA-5.

4. STAGE GROUND SUPPORT EQUIPMENT

This section describes the general concept to be used in development of ground support equipment for checkout of an individual stage. The material has been obtained from various documents and discussions with MSFC personnel. It is presented here as background information to illustrate our understanding of the MSFC concept of stage interface GSE, which is developed for use both with the stage ground support equipment and the vehicle checkout and launch equipment.

The general equipment configuration to be used for checkout of an individual Saturn stage is shown in Figure 4-1. This configuration is applicable not only for the propulsion stages but also for the instrumentation unit which is treated as a separate stage and must meet the same checkout philosophy requirements. Properly, the payload or spacecraft also should fall into this same category so far as checkout requirements are concerned.

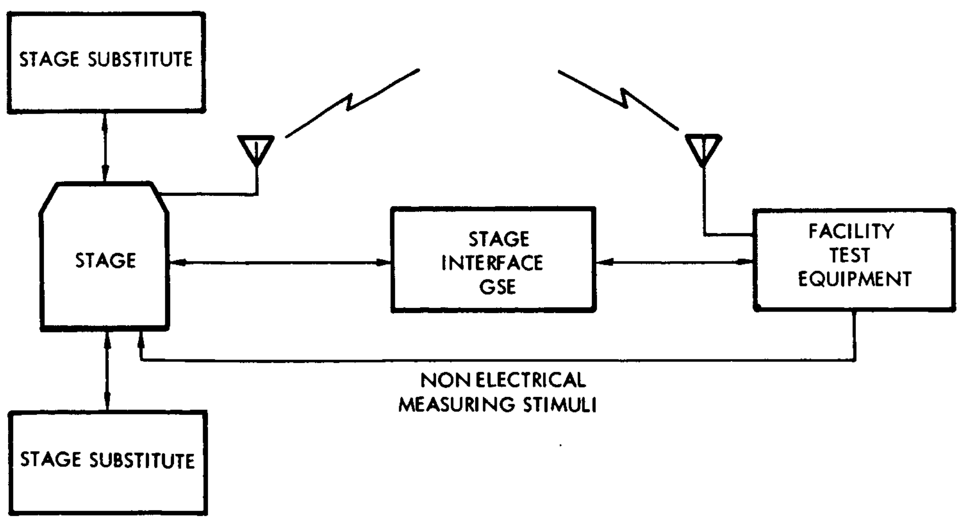

Figure 4-1. General Equipment Configuration for Checkout of Individual Saturn Stage

Note: Copy of MSFC sketch.

As shown, the major elements of equipment used for stage checkout are as follows:

a) Stage interface GSE

b) Stage substitutes

c) Facility test equipment.

The stage interface GSE will be developed as an integral part of the stage design to facilitate proper integration of each stage into all of the required test areas. This stage interface GSE will normally be no more than an electrical distribution system, but in some cases it may contain auxiliary controls and manual monitoring equipment.

Stage substitutes are used to simulate upper and lower interfaces so that all stage operations can be fully evaluated. In the case of the liquid propulsion stages, the substitute will be used in large part for calibration and evaluation of measurement adapter outputs contained within the stage. It is planned that each stage substitute will be developed and furnished by the particular stage manufacturer for which the substitute is named.

The facility test equipment will consist mainly of an operational computer complex and a telemetry ground station. The computer will operate through the stage interface GSE to test the stage while making use of hardline operational measurements. The telemetry ground station will serve to process telemetry data both for direct display and for insertion into the digital computer for automatic evaluation. An additional function of the facility test equipment is to supply known physical stimuli, such as a calibrated pressure, to the vehicle for actuation of the various mechanical signal transducers.

As stated previously, the stage interface GSE will be developed to integrate checkout of the stage into the various test facilities to be encountered from factory to launch. Thus, it must be compatible with the computer complex provided at each stage checkout site and with the computer complex used for vehicle checkout and launch at AMR. At present, there is no plan for standardization of these computer installations in a hardware sense, although the test concept requires that standardized test procedures be used for each site.

Although not of particular significance to this study, it should be noted that the computer complex utilized for stage checkout at each factory site also will be used to control operations of various component test stations. A number of these stations will be set up at remote locations for checkout of such items as electrical components, instrumentation system components, and mechanical components. The exact nature of the test stations and number to be used will vary with individual stage requirements, but it is intended that each station will be operated under program control of the central computer complex.

5. C-1 VEHICLE GROUND SUPPORT EQUIPMENT

This section presents a description of an automation system for the C-1 vehicle. The design is predicated on a basic concept developed by MSFC with emphasis on further definition of the hardware requirements. The approach taken is first to present a description of the equipment configuration required to automate the C-1 launch complex and then to describe in detail the functional requirements for each major unit of equipment. Particular emphasis is placed on the control and display capabilities available to the various test operators.

5.1 General Concept

The various stages of the C-1 vehicle, after passing through a stage checkout area, are physically assembled on the launch pad of Complex 34 or 37. After assembly, the vehicle is tied through umbilical connections to stage interface GSE which distributes test circuitry to a blockhouse area located about 1700 feet away. The blockhouse contains test consoles of the conventional type and serves as a launch control center. Displays and controls in the blockhouse allow manual operation of the total vehicle system. Propellant loading facilities at the pad are operated by remote control from the blockhouse. Measuring stimulus circuitry is provided at the pad to assist in performing whatever mechanical calibration may be required. Conditioning of test signals will be performed by the stage interface GSE at the pad prior to transmission to the blockhouse in analog form.

Beginning with the launch preparation of Saturn SA-5, an operational computer complex will be installed in the blockhouse for operation in parallel with the manually operated consoles. The computer complex will monitor all operations and, at the discretion of the test conductor, will perform some or all of the operations required for checkout and launch of the vehicle. For this study, it has been assumed that telemetry data will be available in the blockhouse both for direct display and evaluation by the computer. If this capability can be provided, it will facilitate a comprehensive checkout of the computer programs and procedures which are designed for combined evaluation of hardline and telemetry data.

5.2 C-1 Automation System

A block diagram showing the general layout of automation equipment for Complexes 34 and 37 is presented in Figure 5-1. As shown, the vehicle consists of the S-I and S-IV propulsion stages, an instrumentation unit, and a payload which will probably be a developmental model Apollo spacecraft. Since the spacecraft and instrumentation unit are both treated as stages, four separate sets of stage interface GSE are used at the pad area.

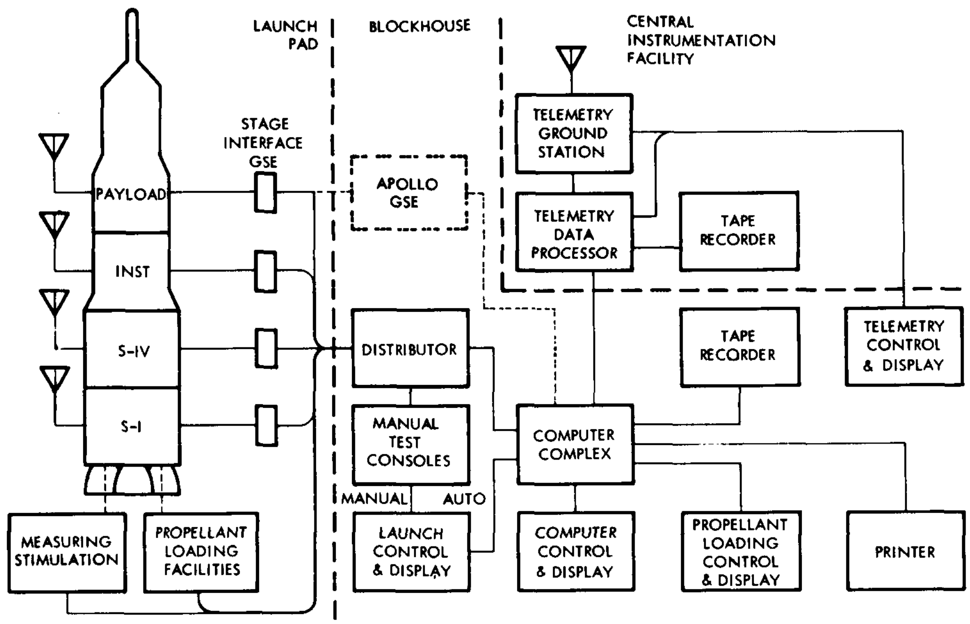

Figure 5-1. Automation and Equipment Layout for Complexes 34 and 37

The manual test consoles used for early C-1 launches are capable of complete checkout and launch of the vehicle. These consoles are of conventional design and consist of a collection of stimuli generators and data measuring equipment, such as signal generators, multimeters, oscilloscopes, etc. Supplementary controls and displays are installed as required to facilitate the test and launch operations.

The computer complex consists of an RCA-110 computer and associated input/output peripheral equipment. Its primary function on Saturn SA-5 is to accomplish prelaunch checkout of the instrument unit. On subsequent vehicles, this role will increase from monitoring general test operations to performing all checkout and launch operations. As shown in Figure 5-1, the computer complex operates directly through the blockhouse signal distributor when communicating with the Saturn vehicle. It is assumed that all signal conditioning needed for this direct connection will be furnished either in the stage interface GSE at the pad or in the signal distributor at the blockhouse. This direct communication without extensive buffering is made possible by a comprehensive set of input/output equipment provided as part of the computer complex.

The computer control and display console enables the test operator, hereafter called the computer operator, to select and initiate tests as well as to monitor and evaluate test results. Displays indicate such items as test status and individual measurement results. A control panel permits insertion of program data into the computer, initiation of various test operations, control of computer operating mode, etc. All test operations are set up and most are physically controlled from this console so that the controls and displays represent the major human factors interface between blockhouse personnel and the computer complex.

The test conductor uses the launch control and display console as a command post for controlling the prelaunch preparation and launch countdown of the space vehicle. In the manual mode of operation, control is exercised in the conventional manner both by voice communication with test operators and by signal interconnection with the manual test consoles. As automation is incorporated, a panel will be added to the existing launch control and display console for direct communication with the computer. This communication is of a rather simple nature, consisting mainly of initiating major operational sequences during launch countdown and of receiving an overall indication of computer status.

The propellant loading console is used for close monitoring of the automated propellant loading operations and for initiation of emergency action as required. Because propellant transfer involves hazardous operations, special displays are provided for detailed step-by-step evaluation of operations performed by the computer. Emergency controls initiate special computer sequences and, when necessary, bypass the computer to initiate a rapid defueling operation. Pertinent information available to the operator includes storage tank pressures and temperatures, valve and pump indications, stage tank pressures and temperatures, propellant levels, etc.

The telemetry control and display console is located in the blockhouse to provide an immediate and comprehensive display of the telemetry ground station status. An operator at this console is responsible for determining the readiness of the telemetry subsystem and reporting this condition to the test conductor. Status information for each data link is available to the operator along with the capability for direct evaluation of such items as received signal strength, modulation characteristics, and general data quality. Selected telemetry data can be displayed in real time for evaluation of vehicle equipment performance and for general troubleshooting operations in the event of automation equipment failure.

A set of Apollo GSE will also be located in the C-1 blockhouse to support launch of early Apollo "boilerplate" capsules. To provide a gradual phase-in of this equipment, it is recommended that physical integration with the Saturn automation system be initiated during the C-1 program. Although the exact nature of the interface cannot be defined at this time, it is assumed that the computer complex will exercise some control over operation of the Apollo equipment, as indicated in Figure 5-1. Details of this interface should be determined as early as possible to ensure development of an optimum approach and to facilitate the necessary design integration.

The foregoing brief description of the Saturn C-1 automation system described the functions of the major units of equipment and the duties of the console operators. A more detailed description of each major unit is contained in the following sections.

5.3 Description of Automation Equipment

This section describes the equipment added to the C-1 blockhouse for use beginning with SA-5. It contains descriptions of the automation equipment shown in Figure 5-1, namely the computer complex, telemetry ground station, launch control, and propellant loading consoles.

5.3.1 Computer

5.3.1.1 Characteristics

The central computer in the C-1 Complex is the RCA 110. This computer is a solid-state machine with a word length of 24 bits. It is serial, with a 936-kc clock and 28.89-microsecond word time. Internal data transfers are parity checked. As an aid to localizing trouble, the computer records the address of the instruction executed preceding the discovery of the error. The high-speed working store of the computer is a core memory of 4096 words, with a read/write cycle time of 9.7 microseconds. In addition to the high-speed working store, the computer is provided with a drum memory. The drum has a capacity of 8192 words and is expandable to 51,200 words. The average access time to any word on the drum is 8.3 microseconds. The computer is basically a one-address machine having 71 wired-in instructions, but it has limited capabilities as a two-address machine. It is equipped with seven addressable index registers. The speed of arithmetic operations including access time is 56 microseconds for addition, 728 microseconds for multiplication, and 868 microseconds for division.

The computer was expanded to handle the various types of analog and digital information utilized in operational checkout and also to generate various commands and data needed to preset and launch the vehicle. The number of inputs and outputs shown in Figure 5-2 are best estimates presently available for those required in the SA-5 through SA-10 requirements.

The peripheral equipment in the present system has inputs for 600 analog d-c voltages that are converted to 10-bit binary numbers accurate to 0.1 percent. The computer complex can receive an analog signal, compare it with a high and low rejection limit, and generate an alarm signal at the rate of 2200 of these operations per second. This capability allows a seemingly continuous check with all of these inputs to be interwoven to any of the various functions and duties of the computer complex on almost a noninterference basis. This peripheral equipment also has inputs for 500 discrete signals. These are On-Off signals that can be scanned and

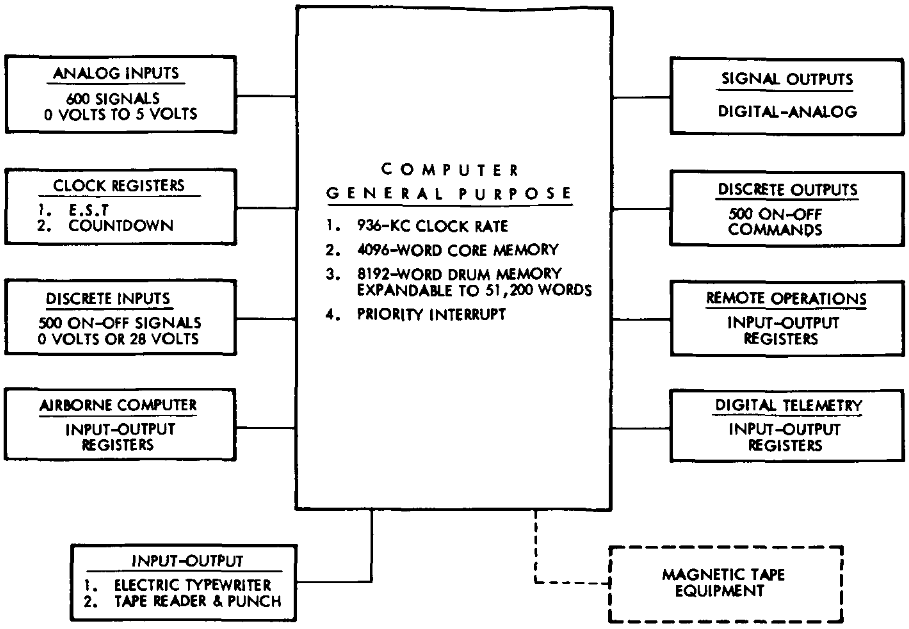

Figure 5-2. Saturn Ground Computer Complex

Note: Copy of MSFC Sketch.

compared to "should be" conditions retained in the computer memory at a rate of greater than 15,000 per second. The sequence in which these signals are scanned is determined by the computer program. The number of points can easily be increased as is the case with the analog signals requiring only a change in the program and addition of logic of the same type as is utilized in the present system.

The system outputs include 500 discrete signals that can be individually controlled by the computer. These can be changed at any time to any configuration as directed by the computer program. The system is also capable of generating an analog signal output. One 24-bit register is used to excite one or two D-A converters. These signals may be used as stimuli for various components under test.

Another register is reserved for the computer-to-telemetry communication link. The computer can send information to or receive information from the digital telemetry system through this register. Similar input-output registers are available for clock inputs, communication with the vehicle guidance computer, and use in remote operations.

The computer is able to retain all information in the event of a power failure. This is somewhat unique for a core machine and is accomplished by holding up power with capacitors long enough to store the contents of all dynamic registers in specific core locations. The program is then restarted from the point at which it was interrupted when power is returned.

5.3.1.2 Interrupt

A feature of this computer which makes it an excellent choice for this application is its multi-priority interrupt feature. The computer program may be broken into several sections, each one having an assigned priority level. Eight levels are available. If an external signal requests a priority level higher than the one being operated upon, the computer will sense this and operation of the new higher level program will start in about 100 microseconds. When this signal is removed, operation is resumed on the next lowest level requested. In this way, the computer may be caused to operate on the program most important at any one time. As an example, the self-check routine could be assigned the lowest priority level and would then run any time the computer has no function in the checkout activity. Use of the multi-level interrupt, however, requires careful consideration in the two areas of device control hardware external to the computer and of the special programming techniques which are required. These considerations are discussed below.

5.3.1.2.1 Computer Control

The multi-level interrupt feature of the RCA 110 provides a very powerful means of control. First, the interrupt feature permits expanded operator control from other than the computer console. In this system, a central computer is surrounded by a battery of input-output devices, all of which can control the computer, so that the computer becomes a timed-shared tool of these input-output devices. The input-ouput devices are designed for vehicle checkout and are not computer consoles in the usual sense. Computer programs are invoked by these input-output devices by means of interrupt as required, but without the operator's direct knowledge of the process.

Second, the interrupt feature permits efficient use of the computer's time. The execution of various test programs will be interleaved as a function of their priority or importance and their demand. Communications with the computer are carefully controlled so that requests for computer time are granted only when the requesting device can make immediate use of this time. Third, a by-product of interrupt control is the elimination of the input-output interlocks, which would normally be required for every device in the system. An input device can interrupt only when there is a clear path into the computer, and an output device can interrupt only when it is ready to accept new information. Also, the use of the term "input-output device" includes another computer.

Inside the RCA 110, the interrupt sequence is precisely defined so that the computer does not become confused when told to stop one job and start another. When interrupt occurs, the contents of all the working registers in the machine are stored. This includes the arithmetic registers, the index registers, and the program counter. This is done so that when the new program is executed, the computer may return to the old program and continue its execution as though nothing had happened. Enough information is stored to remake the interrupted program completely. To make multi-level interrupt control work, the behavior of the devices external to the computer must also be precisely defined when interrupt occurs. For example, suppose that a program is driving a hard copy printer. A partial message has been typed when an interrupt occurs, causing a new program to be executed. On completion of the new program, we now wish to continue typing as though nothing had happened.

A problem exists when the program that is interrupted involves a time-dependent action. An example is when a stimulus is applied to a system and the response is observed a fixed time later; another example is in writing a block of data on magnetic tape. When this occurs, the program must "know" that it has been interrupted. This can be accomplished by having the interrupting routine plant a bit in memory. When the original program is restored, it automatically checks this bit at the end of each time-dependent sequence. If it has been interrupted, the program can then re-cycle and repeat the operation.

It is necessary to have centrally coordinated interrupt control external to the computer, as shown in Figure 5-3. There will be simultaneous demands for computer time which have the same priority. There will be many more than eight devices in the system which can request computer time by interrupt. Therefore, one function of the central control will be anticoincidence, and another function will be control of data flow throughout the system. To achieve the degree of control necessary for multi-level interrupt work, the interrupting devices must be provided with strong ties to the programs. Another function of the central interrupt control will be to provide these program ties.

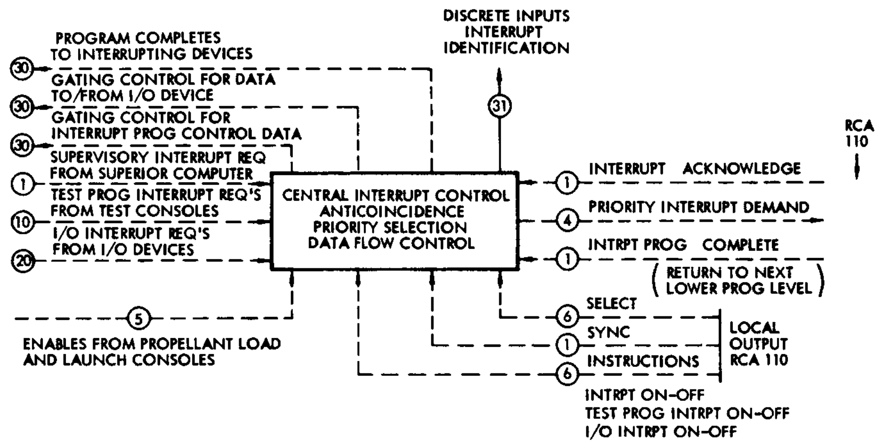

Figure 5-3. Central Coordination of Time-Shared Computer in Interrupt Mode

Other controls for interrupt are also necessary. We must have program control by means of which the computer may turn on and turn off the ability to interrupt of every device in the system. For example, suppose that the computer's maintenance programs have been loaded. Operation now will be from the computer console. It would be undesirable to try to conduct computer maintenance and checkout and troubleshooting with the possibility of an unexpected interrupt from an external source. When checking the external devices, we would wish to have interrupt on only for the device being checked. There are other occasions when interrupt must be turned off. One of these might be during the execution of the executive routine when the test programs are being initialized. Interrupt must be turned off for a device if the permissive conditions for interrupt for that device are to be altered by program means. Multi-level interrupt control, then, will be a powerful tool if its functions are carefully defined, considering all of its ramifications. Failure to do so will result in logical entanglement at a very high rate of speed.

5.3.1.2.2 Programming Techniques

Figure 5-4 illustrates a subroutine invoked by interrupt. The line down the left-hand side of the drawing is the interrupted routine. In this case, a command located in the interrupted routine turns on the ability of device A to interrupt. At a later time, when device A is ready for an immediate transfer of information, the interruption occurs. Before any instructions of the routine for device A are executed, the registers of the computer are stored so that the old program may be remade in the future. The contents of the program counter are stored as the exit line address, the address to which the computer will return after the interruption. After this has been completed, the normal housekeeping and the transfer command for device A proceeds. When device A has been completely serviced, the old program is remade and returned.

The command that returns the computer to the old program has another function, indicated by the dashed arrow labeled "program-hardware link." This is the signal which permits device A to generate another interrupt. Device A must be prevented from generating a subsequent interrupt before execution of the return command. Should this happen, the return line would refer to subroutine A and now the computer will be caught in a tight loop, from which it cannot escape to execute any lower-level program.

If device A is to be shut off, the command which turns interrupt off for device A is executed immediately after the transfer command. This command must always be located within the interrupt subroutine for device A and never externally. On the other hand, the command which turns interrupt on for device A is always located external to the interrupt subroutine. As in the case of the hardware counterpart, the function of the program controls for interrupt must be very carefully defined.

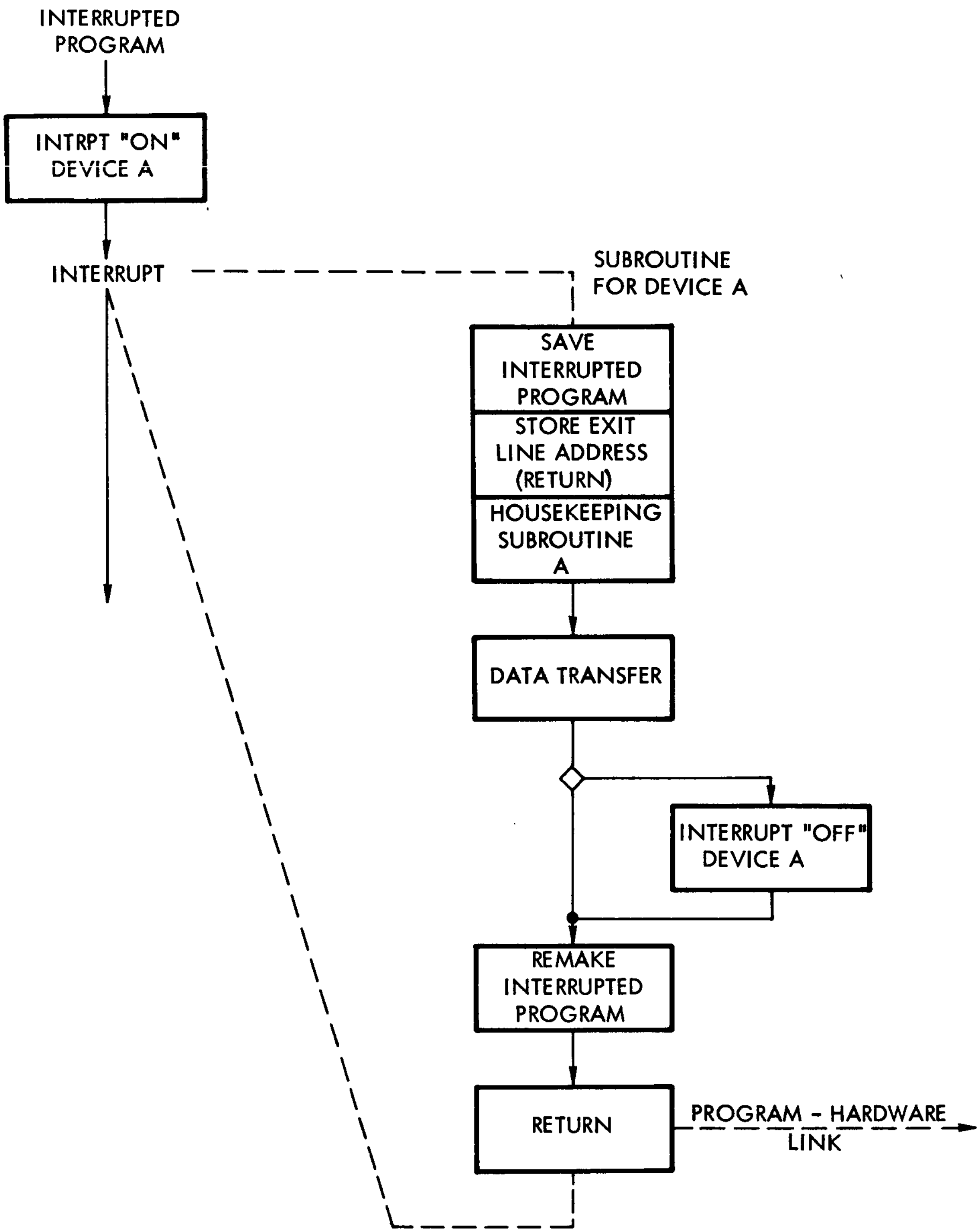

Figure 5-4. Example of Interrupt Programming

5.3.2 Computer Control and Display

Perhaps the most important factor in determining the success of an automatic checkout system is the effectiveness of the man-machine interface. In a system of this type, the concept of "you push the button and the machine does the rest" is completely invalid. Instead, the system must be thought of as an extension of the operator, augmenting his abilities and increasing the scope of his comprehension. In the early stages of the program, every step of the tests should be under direct operator control. As the work proceeds, and the system under test becomes more nearly operational, the operator normally focuses his attention on larger and larger groups of steps, while keeping the capability of going back to a step-at-a-time operation. During all phases, however, the emphasis must be on the operator running the system rather than simply monitoring an automatic device.

Ideally, the man-machine interface should be of such a nature that the operator can be an expert on the system under test, rather than the test equipment itself. There are two other considerations which play a major role in the interface design. These are the flexibility required to meet the major changes that can occur in R and D programs, and the ability to operate the system efficiently and with a minimum of errors during periods of stress, such as during prelaunch countdown.

These considerations, taken together, are reflected by the following requirements:

a) The operator should have the complete system status available to him. The primary display should present the information as a summary, with sufficient detail to conduct the test; however, all details should be available to him on request.

b) The control exercised by the operator must be capable of being varied from a step-at-a-time operation to the control of a set of tests taken as a group.

c) Communication between the system and the operator should be simple and in a form that requires minimum interpretation by the operator.

d) The displays and controls must emphasize flexibility of usage to meet changing requirements and conditions.

In addition, careful attention must be paid to human factors in the actual equipment design, as well as division of responsibility and duties if more than one operator is employed. An overall sketch of a console layout is shown in Figure 5-5; the individual panels are discussed in detail in this section. It must be emphasized that all layouts are purely functional and indicative; no attempt has been made at this time to apply human engineering principles.

5.3.2.1 Test Controls

With the fully automatic Saturn system, every action must eventually either control the computer or be monitored by it. Both the propellant loading console and the launch control console directly initiate and control computer sequences. However, the most direct and flexible communication with the system is through the computer control and display console. This is therefore considered the primary computer control station.

A complete system test is made up of a set of routines or test sequences, some of which may be partially or completely manual. A test sequence consists of a set of test steps, arranged in an orderly procedure, which when taken together completely or partially check a system or subsystem, and perform fault diagnosis or fault isolation.

The test step represents the basic unit of thinking of the test operator, and consists of such actions as "apply stimulus x to point y" or "measure voltage x and compare against limits y and z." A test step is a computer subroutine implemented by several program steps. Communication between the operator and the system should not be below the test step level. A more detailed knowledge of the equipment operation should be required only when a malfunction occurs in the computer or auxiliary equipment. While the operator must have a means of validating the operation of the test equipment, detailed diagnosis and repair should be handled by a specially trained crew.

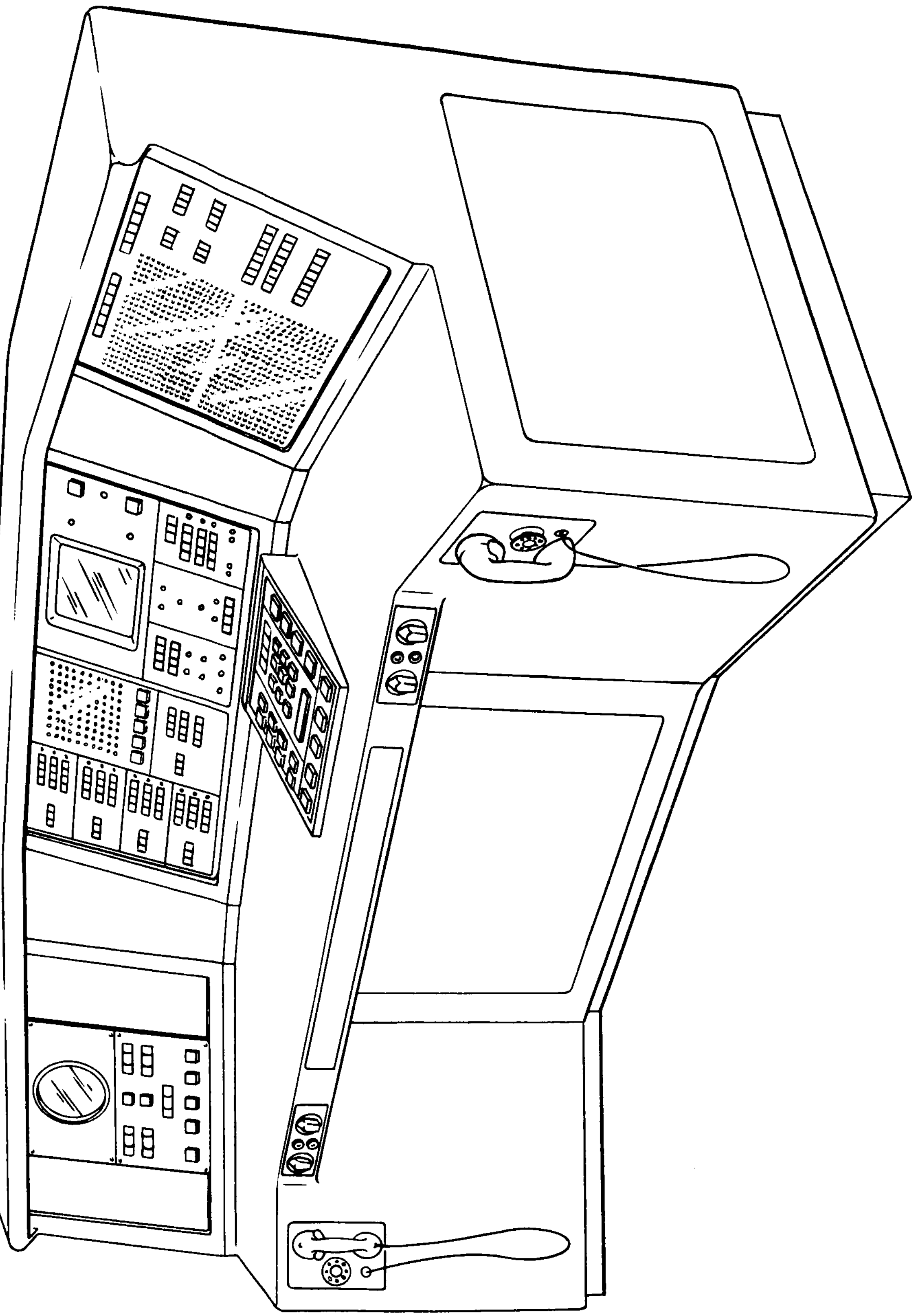

Figure 5-5. Computer Control and Display Console

The test console has therefore been designed for the control of test sequences and steps by the computer operator. The computer console itself is never used, except during maintenance and system turn-on.

A diagram of the basic test sequence control panel is given in Figure 5-6. The controls fall into four groups: the keyboard, entry controls, sequence controls, and equipment status controls.

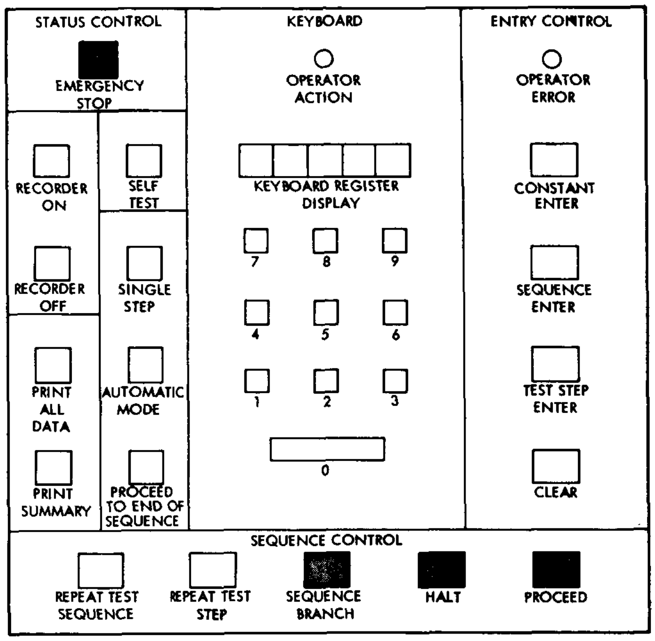

Figure 5-6. Test Control Panel

The keyboard and entry controls are used for initiating test sequences and test steps. A sequence identification number is typed in on the keyboard. This number is displayed directly above the keyboard as it is typed. The "sequence enter" button is then pressed, causing the computer to select the appropriate sequence. To select a particular test step of a sequence, the sequence is first selected as above, and then the test step number is entered. Pressing "test step enter" causes this step to be selected by the computer. In either of the above cases, pressing an "enter" does not initiate the sequence or step. This is accomplished by the "proceed" button discussed below. "Constant enter" is used to fill or change special constants (such as measurement limits) under operator control. This is accomplished by selecting the appropriate sequence and test step, as described above. The constant is then filled using the decimal keyboard, and "constant enter" is pressed. If the operator attempts to enter a constant not under his control, the operator error light is lit as described below.

In the event of an error, the keyboard register may be cleared by the "clear" button. The "operator action" light indicates that the system is in an "idle" condition, so that information can be entered from the keyboard. Every entry or operator action is checked by the computer for validity; in the event of an invalid operation, action stops and the "operator error" light is lit.

Sequences normally proceed either a step at a time or automatically until an out-of-tolerance condition is detected or until an end of sequence is reached. In any event, the "proceed" button is utilized to initiate the next action. If in an automatic mode, the sequence can be halted by the "halt" button.

If a malfunction or out-of-tolerance condition is detected during a sequence, the operator normally has a choice of either proceeding with the sequence or branching to a diagnostic (or other) routine. The "sequence branch" is used to implement this choice; it also provides a high degree of programming flexibility by implementing operator decisions.

Two controls cause the program to repeat: "repeat test sequence" resets to the beginning of the sequence, and "repeat test step" causes the program to repeat the last step. In the case of "repeat test sequence," the computer must automatically perform such housekeeping operations as resetting any stimuli to their initial condition.

The status controls are used to select the modes of operation and are illuminated to give mode indication. Three of the buttons are interlocking, and are used to select either a step-at-a-time mode ("single-step mode"), the "automatic mode," where the operation proceeds until a malfunction or out-of-tolerance condition is detected, or "proceed to end of sequence" which does not halt inside of a sequence. The latter would be used when an overall summary of all malfunctions is required.

"Self test" can be used at any point in a test sequence, and is used to interrupt a sequence, go into a self-test routine, return to the point at which the original sequence was interrupted, and halt.

The printer associated with the console is normally on at all times to provide a complete record of tests. "Print all data" is used to select a complete printout, while "print summary" is used to print the minimum of information required to record and summarize a test. "Recorder on" and "recorder off" are used to control the recording of test data on magnetic tape.

"Emergency stop" is used under those conditions where it is necessary to quickly de-sequence the system. This control causes the computer to turn off all test devices and go into an emergency shutdown, such as killing all power to the system under test. The exact procedure is determined by the computer and would be a function of current systems status. The computer also should have the power to initiate this action automatically, should it detect the need. In this case, the light would be illuminated under the control button and an alarm would be sounded. In all cases, the computer initiates the information retention subroutine previously discussed in Section 5.3.1.1, thereby permitting the program to be restarted at a later time.

5.3.2.2 Test Display

The displays are divided into four panels of a three-bay console, as shown in Figure 5-5. These panels are: Sequence and Summary, Static, Dynamic, and Data Status, and are described below.

5.3.2.2.1 Sequence and Summary

A diagram of the sequence and summary panel is given in Figure 5-7. The displays fall into four groups: sequence status, test summary, measurement results, and operational information.

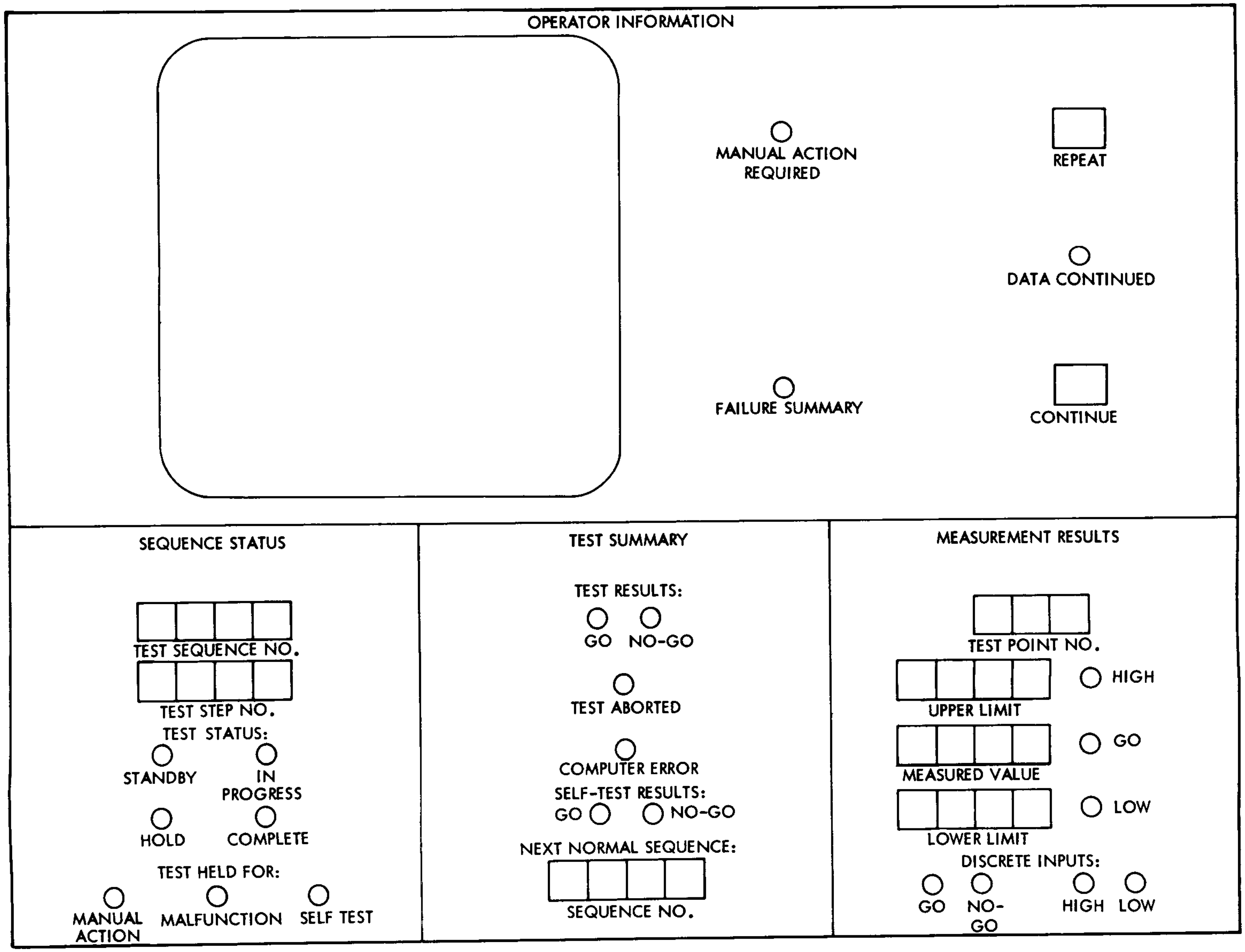

Figure 5-7. Sequence and Summary Panel

The condition of the computer in regard to the current sequence is displayed by the sequence status group. A decimal readout indicates a test sequence number and the test step number within the sequence. A group of four lights indicates the test status: "standby," "test in progress," "hold," and "test complete." If the "hold" light is on, one of the three lights indicating the reason for this hold will be illuminated: "manual action," indicating an action required by the operator; "malfunction," indicating a malfunction or out-of-tolerance condition that has been detected by the computer; and "self-test," which indicates that the operation of the sequence has been interrupted for a self-test procedure.

The results of a test step are shown on the measurement results group. The test point number is a decimal readout indicating the specific test point being measured at this step of the sequence. In addition, a decimal readout is made of measured value at the test point, and upper and lower limits for the value are also displayed. "go," "no-go-high," or "no-go-low" lights are illuminated as appropriate. For discrete inputs, the input is indicated as being either "high" or "low," and in addition, as "go" or "no-go."

The test summary group of lights are illuminated only at the end of a sequence. They indicate a total sequence "go" or "no-go," which is a summary of the individual measurements made in the sequence. There is also a test abort light as well as a "computer error" light, which is lit when the computer detects an error in its own operation. Where a self test has been called out by the operator, the results are indicated by a "self-test go" or "no-go." In addition, there is a decimal readout of the next usual sequence number. This indicates to the operator the sequence normally following the current one.

A primary requirement in designing a man-machine interface of this type is to provide the operator with sufficient information to allow him to take action as required, without burdening him with superfluous details. This requirement, however, is often in contradiction to that of providing complete, comprehensive system test results. To help solve this problem, an operator information display group has been provided. The principal element of this group is an alpha-numeric Typotron type of display tube. Using this display, the computer can signal the operator with English language statements of the action required or with brief summaries of the condition existing in the system. This display is, therefore, used to supplement the printer, which provides hard copy of a considerably more detailed nature.

The information displayed falls into two major categories: The first is a statement of a manual action required by the operator, such as "manually apply stimulus X to point Y;" the second category is the summary of failure information, or test status, which is displayed at the end-of-test sequence. In the event that the amount of data to be displayed exceeds the capacity of the tube, a "data continued" light will be illuminated below the display. By pressing the "continued" button, the operator can then call up the next frame of data to be displayed. The "repeat" button calls back the last frame.

5.3.2.2.2 Static

Static tests are those in which a measurement is made of the static or quiescent state of a certain parameter. Temperatures, pressures, voltage or current levels, and positions of mechanical components are typical measurements of this category, in which no external stimuli are required to perform the test.

A basic building block of the computer test program is a test point sampling routine. This program is automatic and requires no assistance from the operator. In a repetitive cycle, it samples the entire measurement list (hardline and telemetry, digital and analog, and ac and dc), storing the quantities in a temporary memory for subsequent usage.

This data can then be used in several ways. Probably the most common use is that of comparison against stored limits. These limits can be fixed, determined by computation from other measurements (such as temperature or power supply voltage), or manually inserted by the operator.

The display of out-of-tolerance measurements is made to the operator by a matrix of lights, as shown in Figure 5-8. Each light corresponds to a specific parameter. If this parameter is out of tolerance, the light is lit. Up to 600 parameters may be displayed, in 6 groups of 100 each. The groups would normally correspond to vehicle stages or major subsystems.

To identify a particular out-of-tolerance (or other) parameter, the lamp assembly is pressed. This causes the computer to read out the current value of the parameter, the upper and lower limits, a "go-no-go" indication, and an identification number. These are displayed on the decimal readouts shown beneath the lamp matrix.

Additional readouts are provided at the left of the panel for continuously monitoring the values of specific parameters. In this case, the parameters are selected by setting in an identification number on digiswitches.

For some measurements, it will be desirable to have the limits under operator control. These limits are entered using the decimal entry keyboard shown in Figure 5-6. Program interlocks should be provided to prevent changing critical preset limits.

5.3.2.2.3 Dynamic

Provision must be made, even in an automated system, for applying a stimulus to the system under test and observing the dynamic response. Amplifier gain, network transient response, inertial components transfer functions, and transducer response are typical measurements of this category.

The detailed generation of the stimulus is controlled by the computer. When a test step is reached in the test sequence, the stimulus may be applied either automatically or by the operator through the dynamic test panel shown in Figure 5-9. Here, the operator has pushbutton selection of "standard" stimuli, such as sinusoids, ramps, or other waveforms. The magnitude of the stimulus also can be set in by the operator. A decimal readout of the stimulus value and address, as well as the response value and address, is provided. In addition, a dual-beam oscilloscope displays both the stimulus and response for visual analysis.

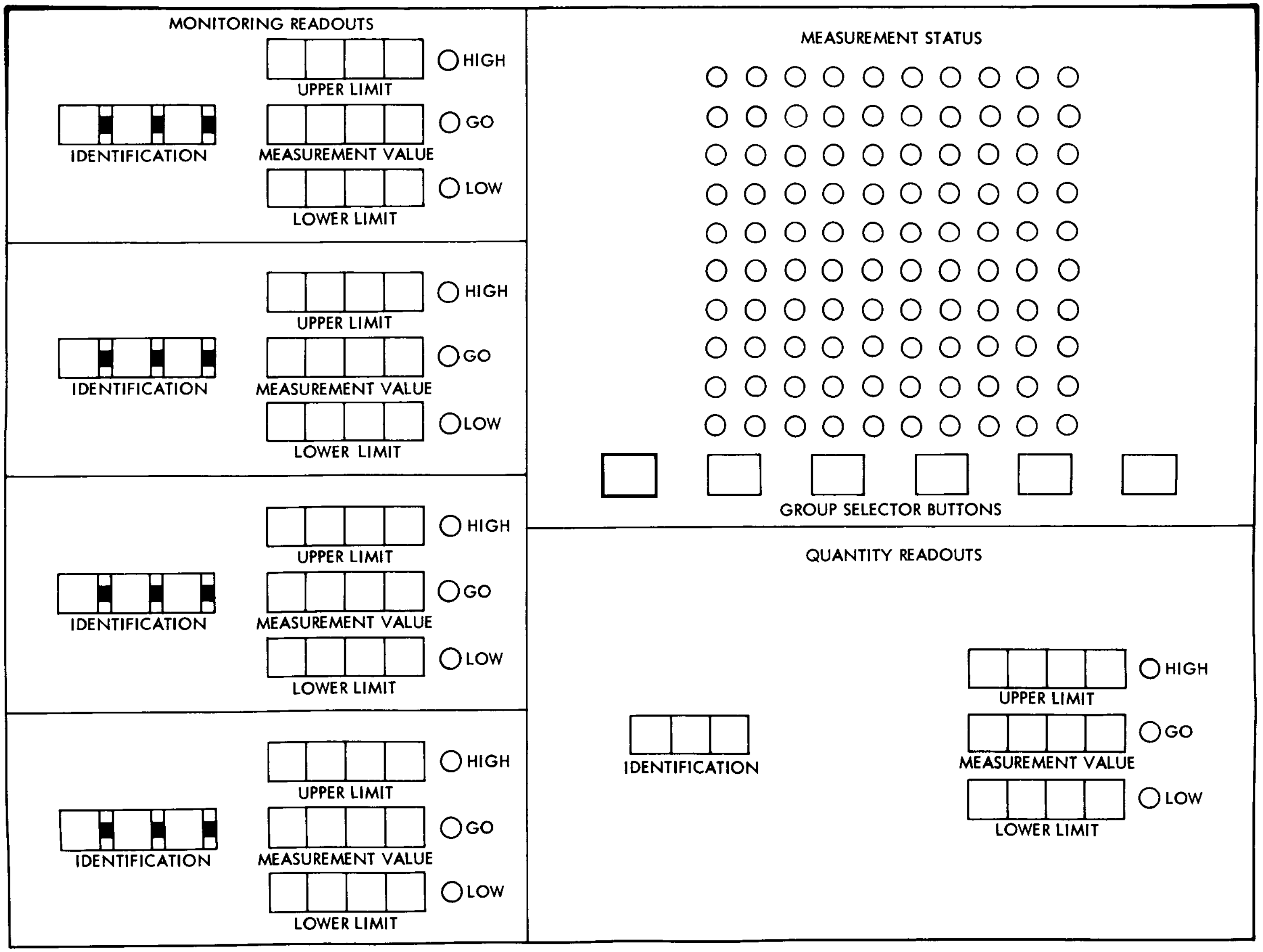

Figure 5-8. Static Test Display Panel

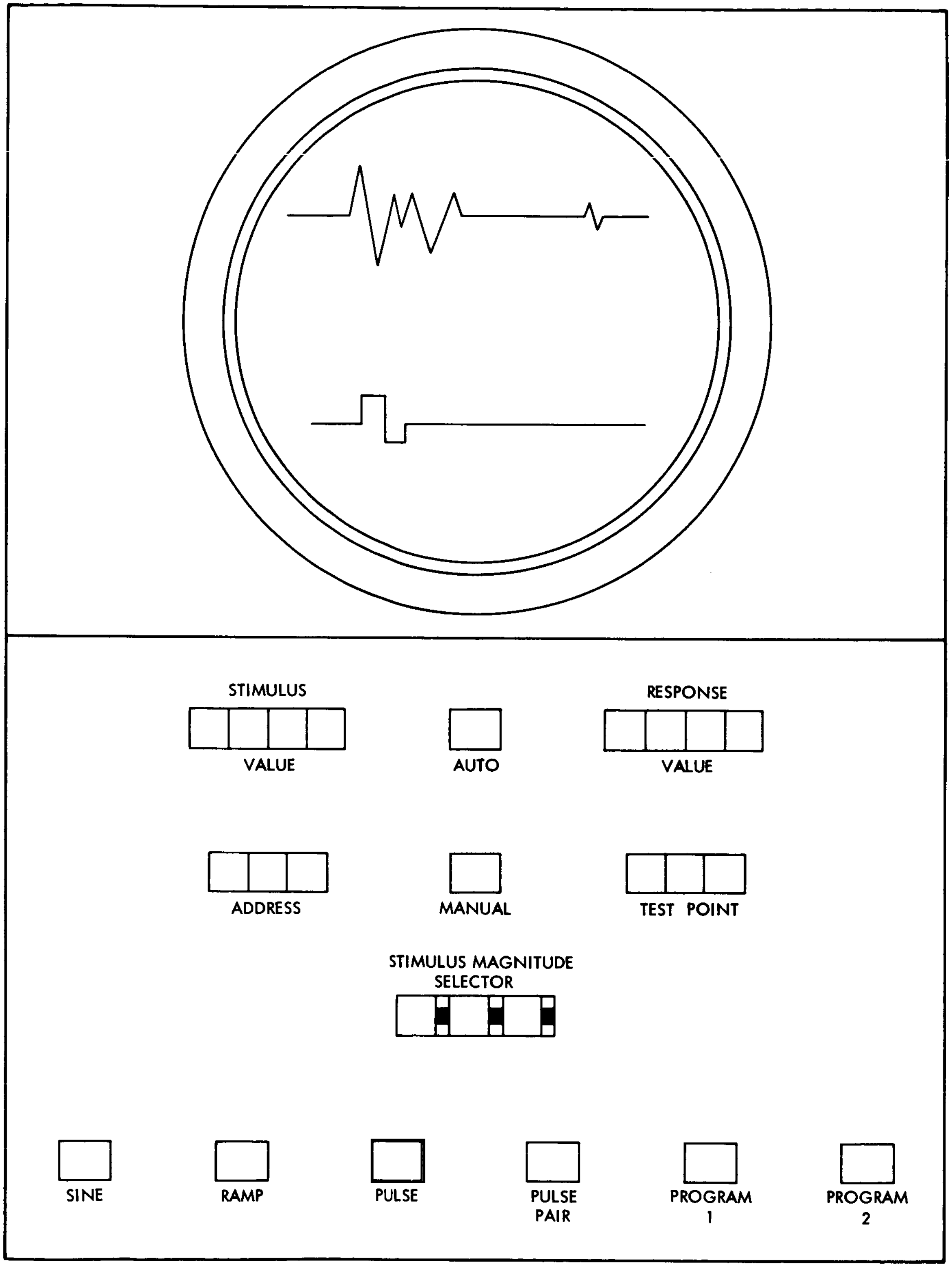

Figure 5-9. Dynamic Test Panel

5.3.2.2.4 Data Status

The overall status of the system must be available to a wide variety of personnel associated with the checkout and countdown. Of direct concern to the computer operator are the states of all discrete inputs and outputs to the computer, the registers communicating with the airborne computer and the telemetry, and the identification and values of the analog input and output. These may be displayed on a panel similar to that shown in Figure 5-10. In the case of the airborne computer and telemetry register displays, the indication could be binary.

No requirements are placed on the computer by these displavs, since the data to be observed are input and output lines and all equipment necessary to drive the displays is contained in the console.

5.3.2.3 Computer Tie-In

The test control panel drive is illustrated in Figure 5-11. Fifteen of the manual controls on the test panel result in program interrupts. All of these programs have the same priority (except for emergency stop, which is a high-priority program). These requests for interrupt enter the interrupt control and test sequence interlocks. If permission for testing has been received from the launch control console, these requests will be passed on to central interrupt control. The interlocks will ensure correct operator procedure; that is, an improper series of manual operations will not produce a request for computer interrupt. Such a sequence will energize the operator error indicators.

The 15 interrupt requests will be "OR-ed" together at the central control and result in a single interrupt request in the computer. They will be differentiated from one another by discrete inputs from the central control to the computer. Permission from the test conductor comes via the select instruction and sync line from the local output of the RCA 110. Program discovery of a condition which demands operator action will result in energizing the operator action indicator from the discrete output of the RCA 110.

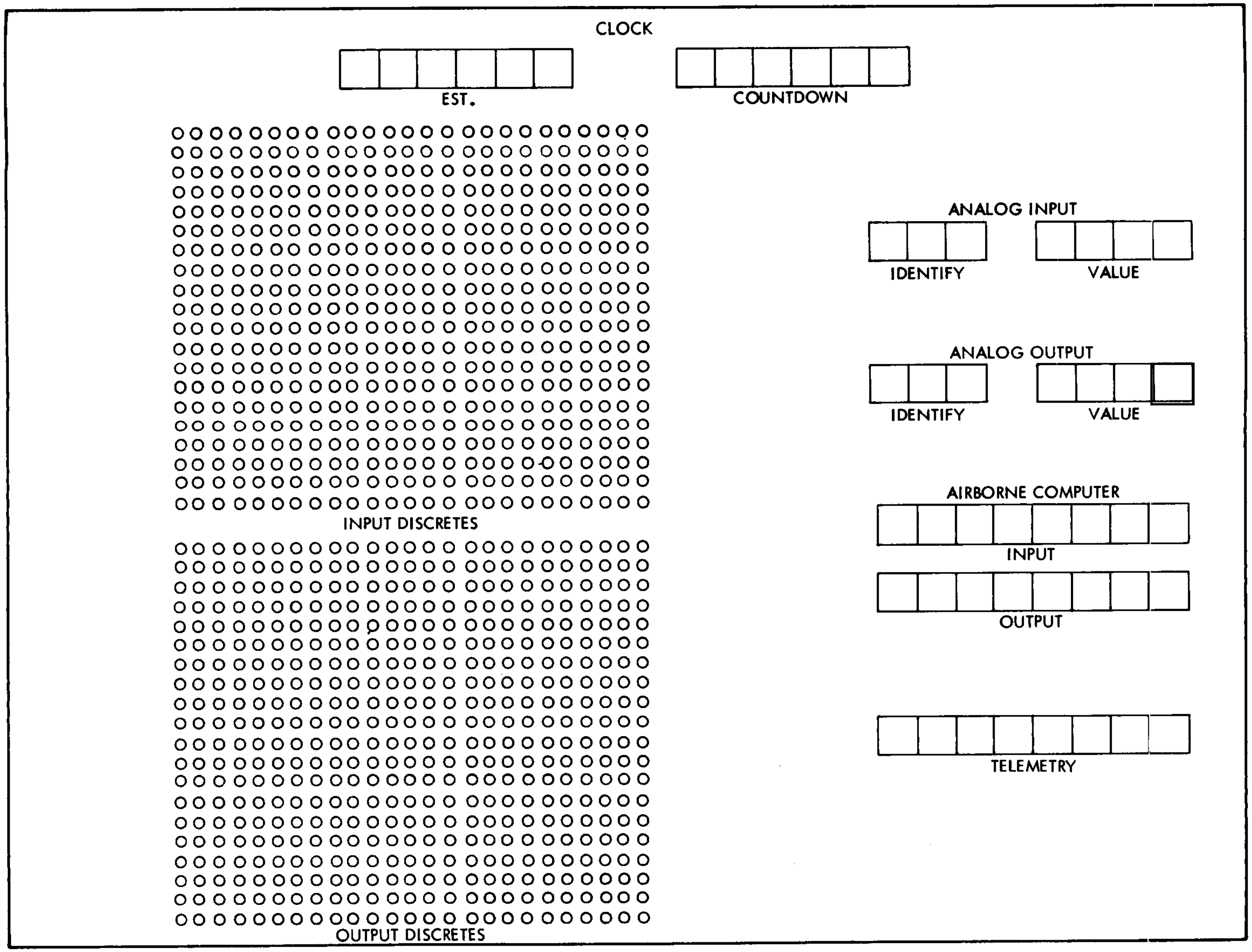

Figure 5-10. Data Status Display

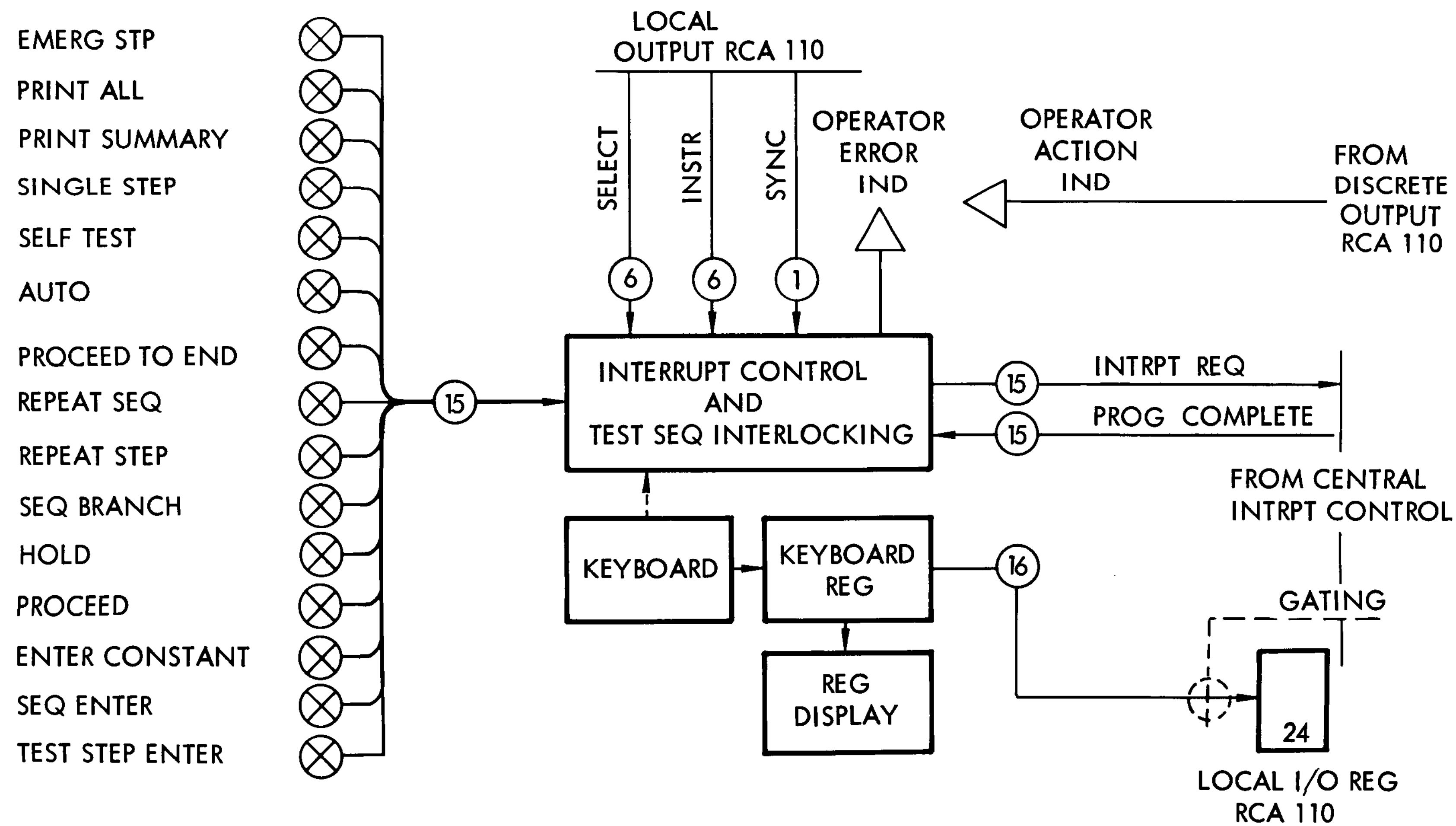

Figure 5-11. Control Panel Drive

The keyboard register and register display are shared by the various programs initiated on this test panel which require manual digital inputs. The operator loads the keyboard register before calling out the program by interrupt. The sequence is interlocked so that it cannot be reversed. Such reversal would cause nonsense to be read into the computer.

This display panel drive is illustrated in Figure 5-12. Most of the indicators on this display panel are driven from the discrete outputs of the RCA 110. The Typotron display and the digital display are driven from a 24-bit input-output register of the RCA 110. A single 24-bit word to the Typotron control contains x, y coordinates and the character code. A single 24-bit word to the digital storage and display contains the display address and coding for four decimal digits. The test display panel may generate two program interrupts in connection with the Typotron. One of these interrupt requests is for a repeat of the previous message. The other interrupt requests the computer to deliver the next message.

The static test display drive and control is illustrated in Figure 5-13. In this display, the operator selects the area of the vehicle which he wishes to observe. He may observe the results of up to 100 test points in any of the six areas which he may select. The indicators are driven from the discrete outputs of the RCA 110. An indication means that the computer has detected a fault condition at one of the test points in the area selected for observation. The operator may request more detailed information about the quantity. He does this by pushing the indicator, which is also a switch. The output of all of these switches is "OR-ed" together to generate a computer interrupt. When the interrupt occurs, the program will survey the indicator lines 24 at a time via the remote operations input-output register. Interrogation produces a digital display of the upper limit, the measured value, the lower limit, and the identity of the test point. If the operator wishes to alter the value of the upper limit or lower limit, he may do so by entering the new value in a register with the keyboard described above. Then, a special interrupt request is generated which calls out a subroutine to plant these new values in the program.

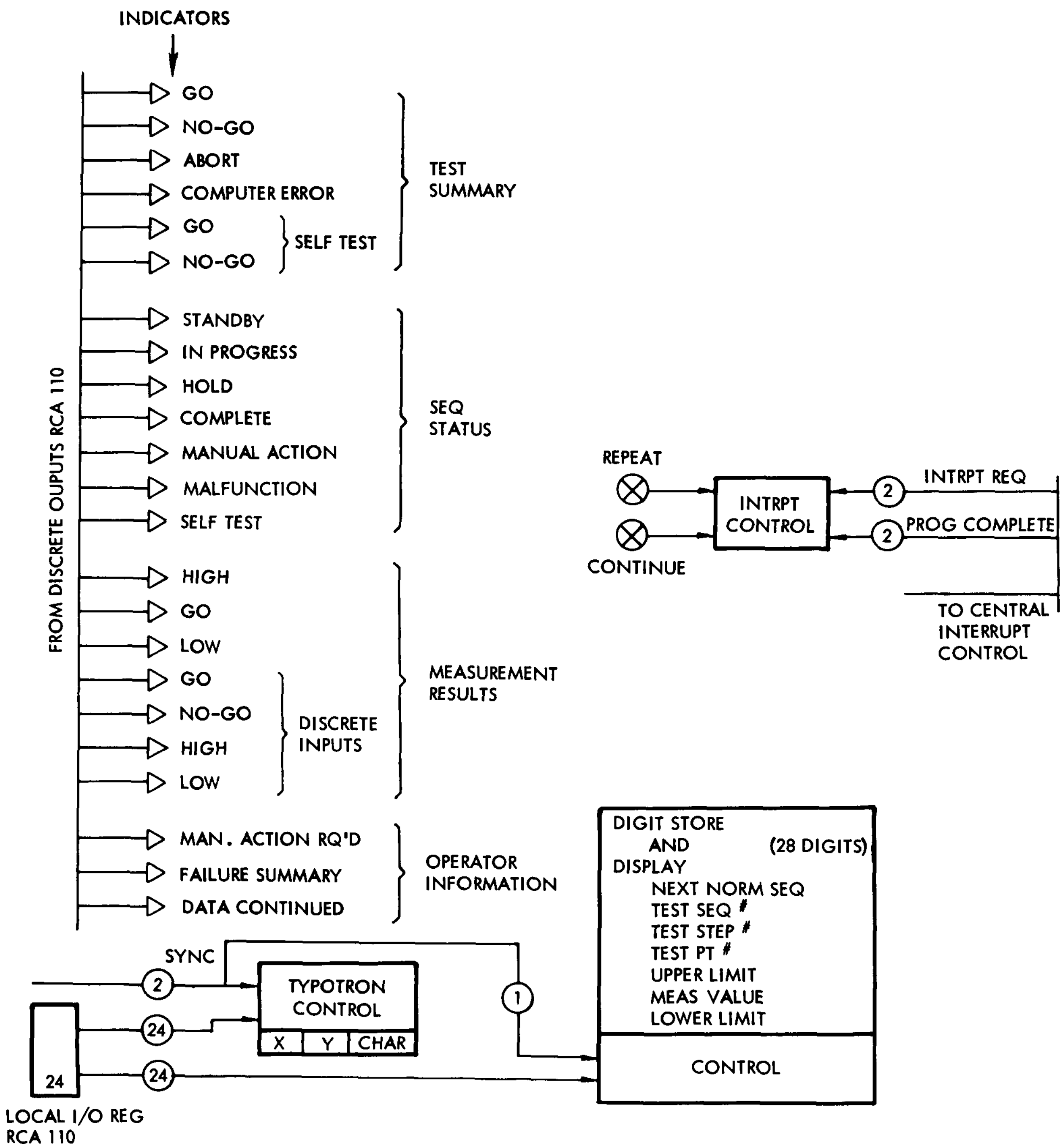

Figure 5-12. Sequence and Summary Display Panel Drive

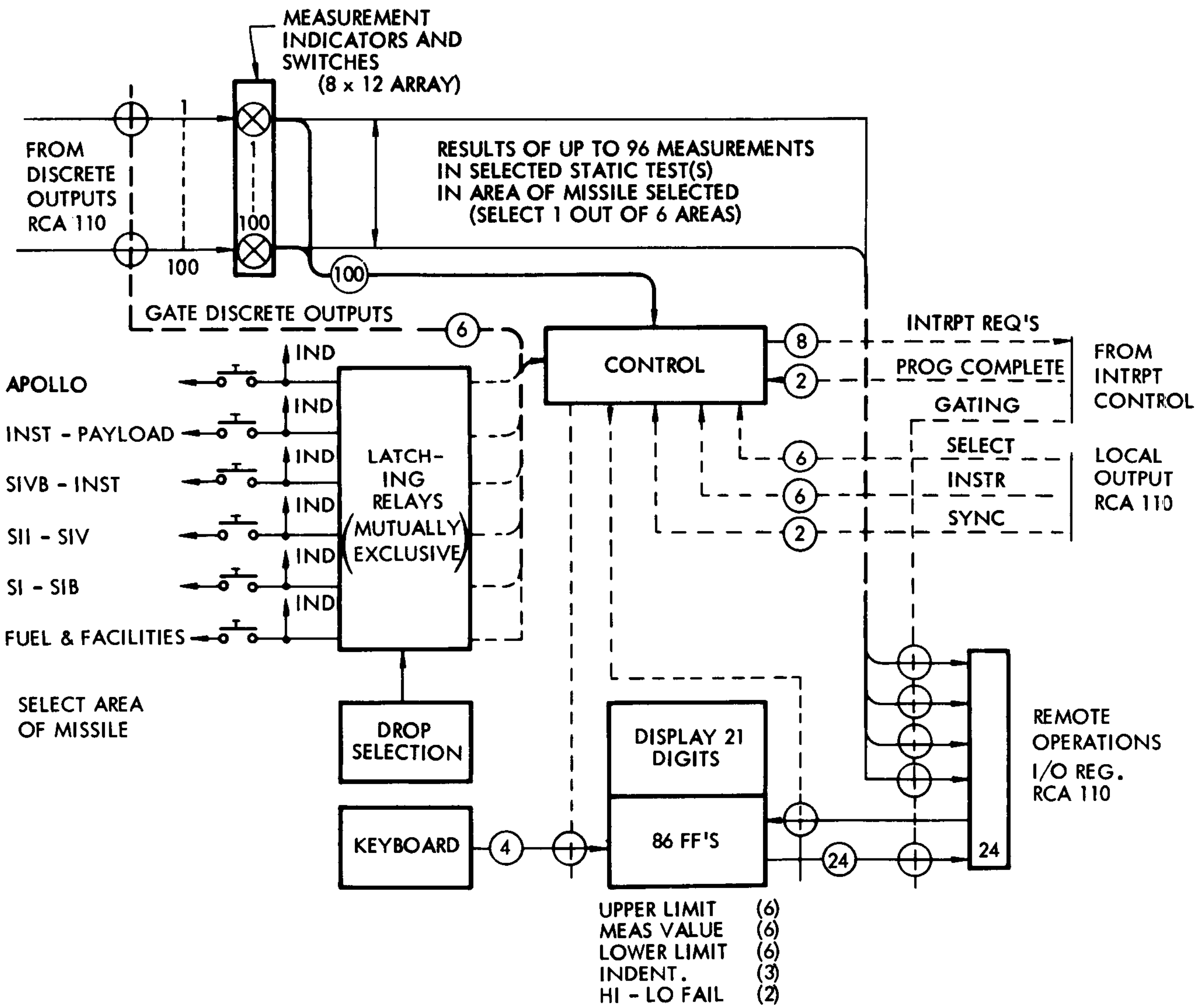

Figure 5-13. Block Diagram of Static Test Display Drive and Control

The dynamic test display drive and control is illustrated in Figure 5-14. Two three-position digiswitches will be used to address stimuli to points in the rocket. The first of these specifies the point to which a stimulus will be sent. This is done by decoding the output of the switches. These outputs are used via the computer to control gates in the distributor, which switch a single output from a digital-to-analog converter to the various input points in the vehicle. The digital-to-analog converter is driven by function generation programs in the computer that are invoked by the interrupt control. Function selection is provided on the panel.

The other three-position digiswitch specifies a test point in the rocket to be monitored. This address enters the computer on program command via the remote operations input-output register. The response itself enters the computer via the analog inputs to the RCA 110. The response is not measured directly, but is filtered by the computer and is displayed via a digital-to-analog converter which drives the scope display. Digital information from both converters is displayed as digital values of stimulus and response.

In general, interrupt is used for controlling the sequence of test programs so as to invoke special subroutines for display and interrogation, rather than for programming periodic interrogation. Programmed periodic interrogation involves a program survey of a very large number of discrete inputs. The use of interrupt, however, frees the computer from this requirement. Therefore, the only load offered to the computer by the displays is the routine output of measured values as they are scanned.

5.3.3 Telemetry Ground Station

5.3.3.1 Requirements

The telemetry ground station includes several requirements which differ from the usual simple collection of data. As a part of an automatic checkout facility, various channels of telemetry data are automatically examined by a computer. Based on the results, a "go" or "no-go" decision is made prior to launch. Certain dynamic channels, which

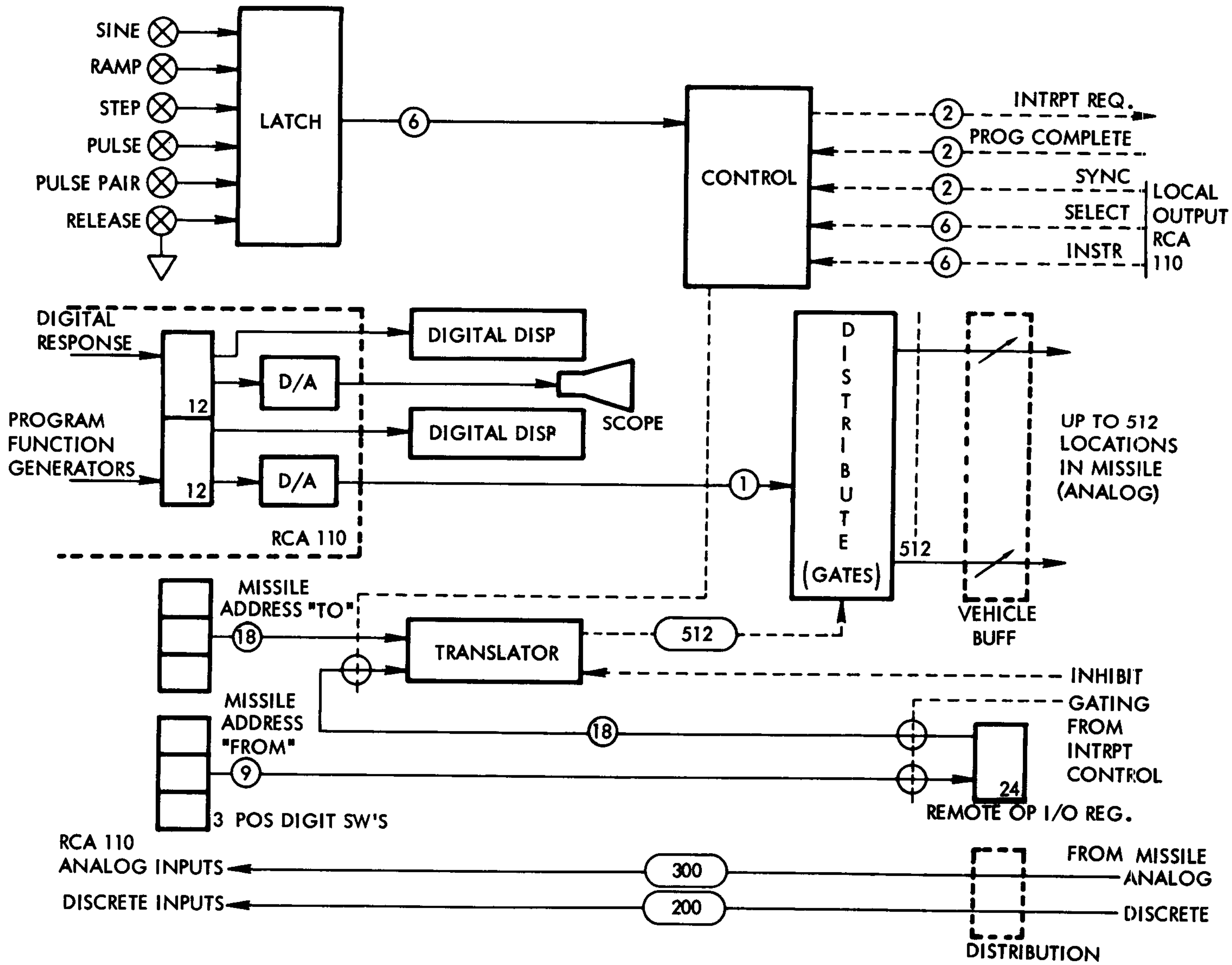

Figure 5-14. Block Diagram of Dynamic Testing Drive and Control

normally provide data derived from the flight environment are examined for proper static condition. Upon examination, these channels indicate a "go" or "no-go" status. Also included in the telemetry system are a number of channels of guidance information in digital form from the airborne guidance computer. These channels are used to indicate the readiness of the guidance system.

For the flights before the installation of the checkout computer in the blockhouse, telemetry data is merely examined visually and recorded. Beginning with SA-5, telemetry data is also fed into the computer. However, operator monitoring of telemetry data is still a requirement and a desirable capability. For these reasons, the telemetry station must also be able to display the telemetry data visually. The ground station must be able to perform the following detailed functions:

a) Decommutate pulse-amplitude-modulation data

b) Decode pulse-code-modulation data

c) Decode pulse-duration-modulation data

d) Demodulate frequency-multiplexed data

e) Decode guidance computer digital data

f) Demodulate frequency-modulated, r-f carriers

g) On computer command, deliver certain "blocks" of the above data to the computer

h) By manual control, display certain "blocks" of the above data visually.

A large portion of the foregoing functions can be performed by "off-the-shelf" components used on other programs.

A simplified block diagram of the telemetry ground station is shown in Figure 5-15.

The station block diagrams and interconnecting wiring are presented in Figures 5-16 through 5-23. The telemetry control and display console is shown in Figure 5-24, and a detailed view of the data display and control panel appears in Figure 5-25.

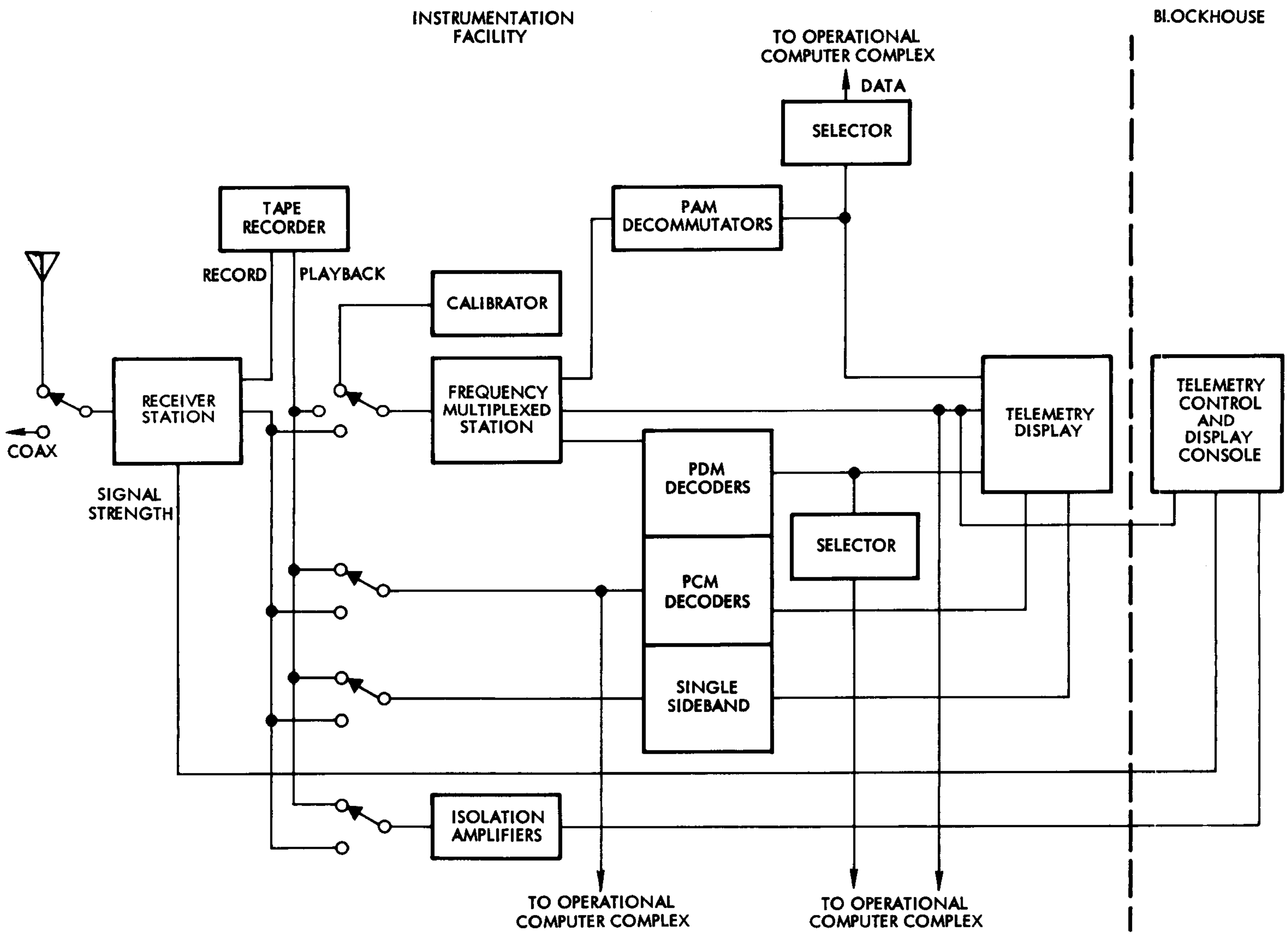

Figure 5-15. Block Diagram of C-1 Telemetry Ground Station

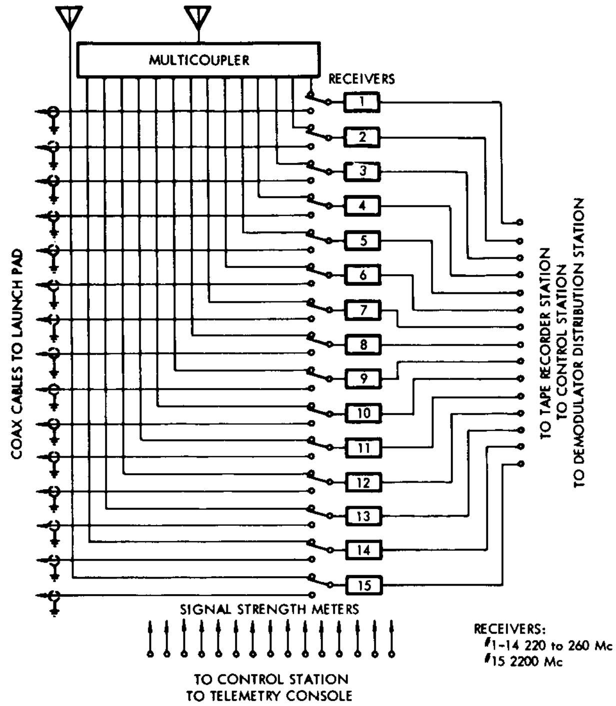

Figure 5-16. Block Diagram of Receiver Station

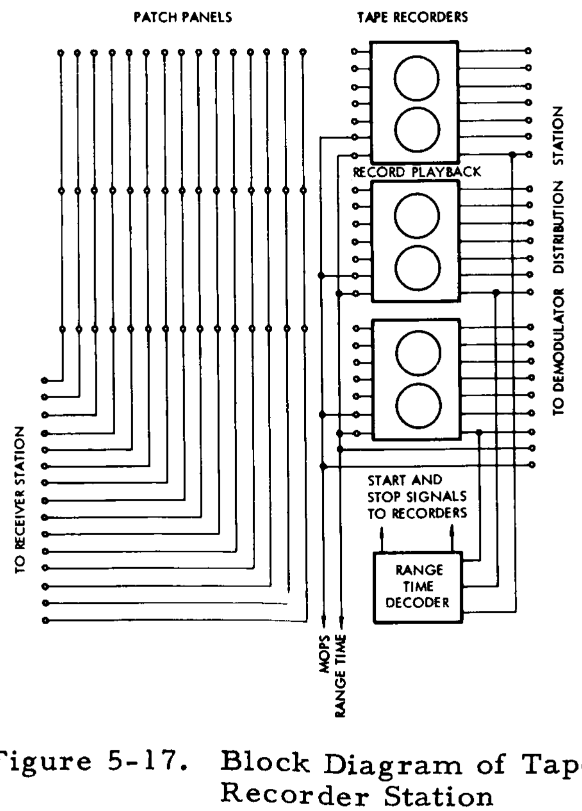

Figure 5-17. Block Diagram of Tape Recorder Station

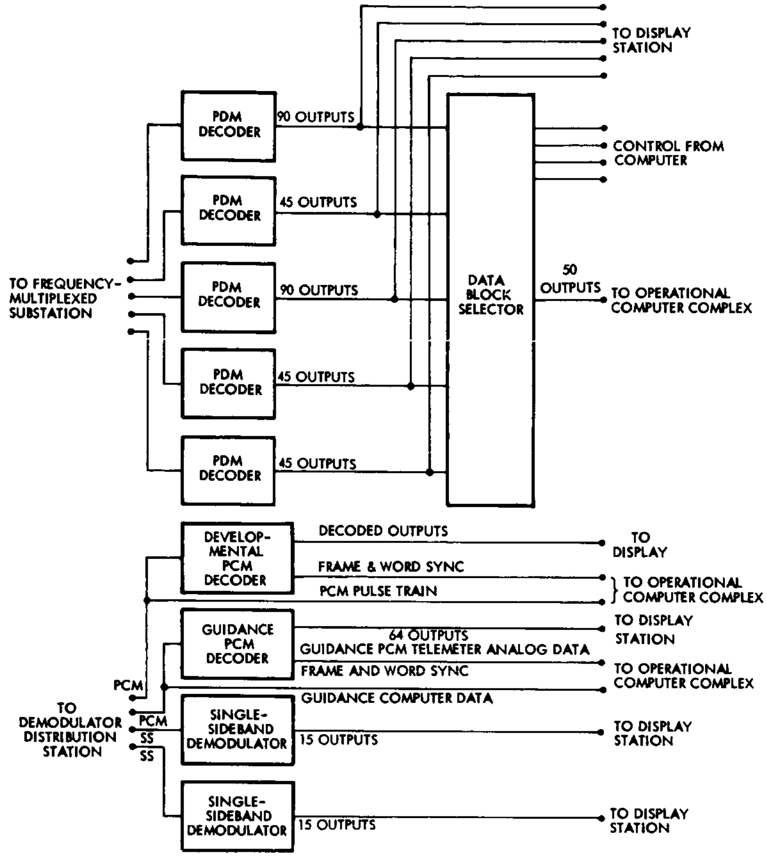

Figure 5-18. Block Diagram of Decoder Substation

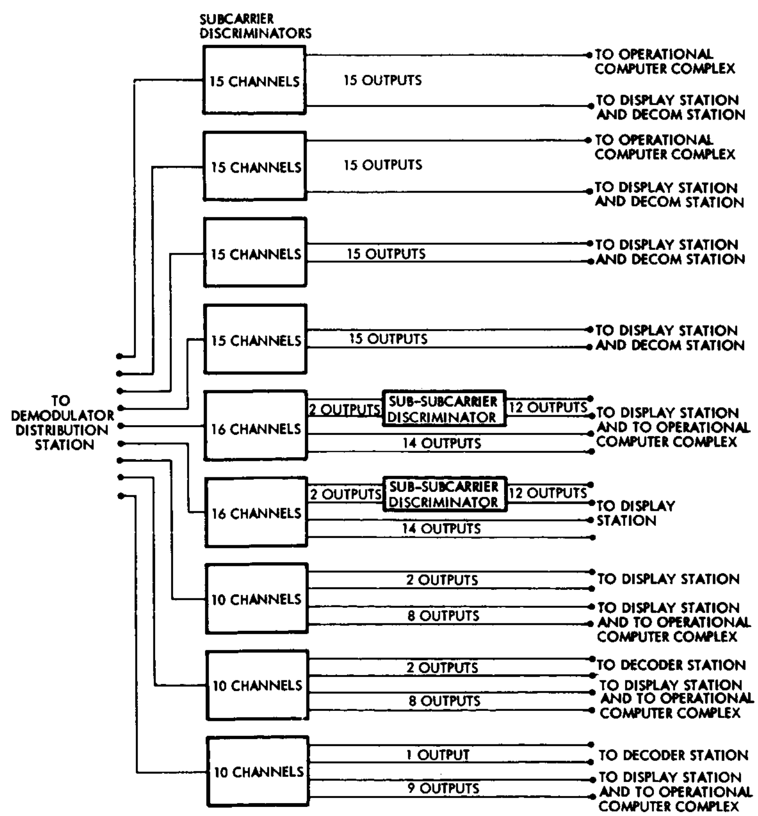

Figure 5-19. Block Diagram of Frequency-Multiplexed Substation

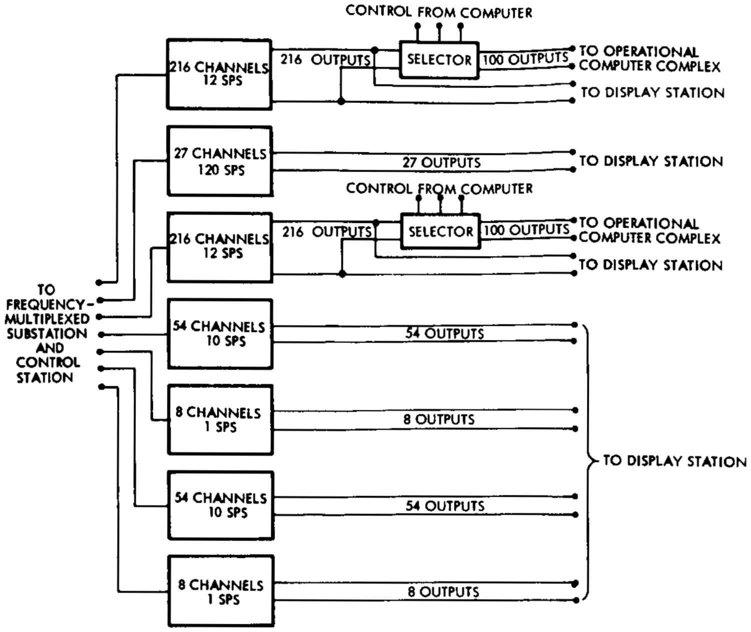

Figure 5-20. Block Diagram of Decommutator Station

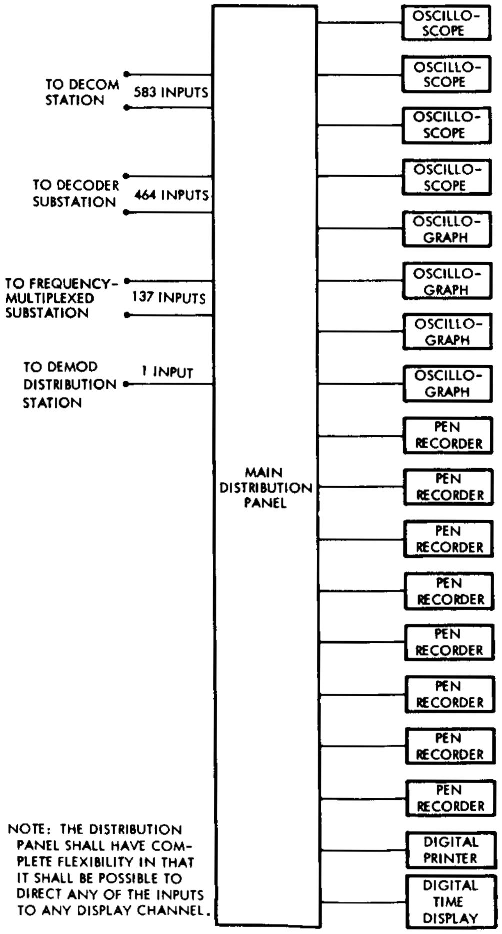

Figure 5-21. Block Diagram of Telemetry Display Station

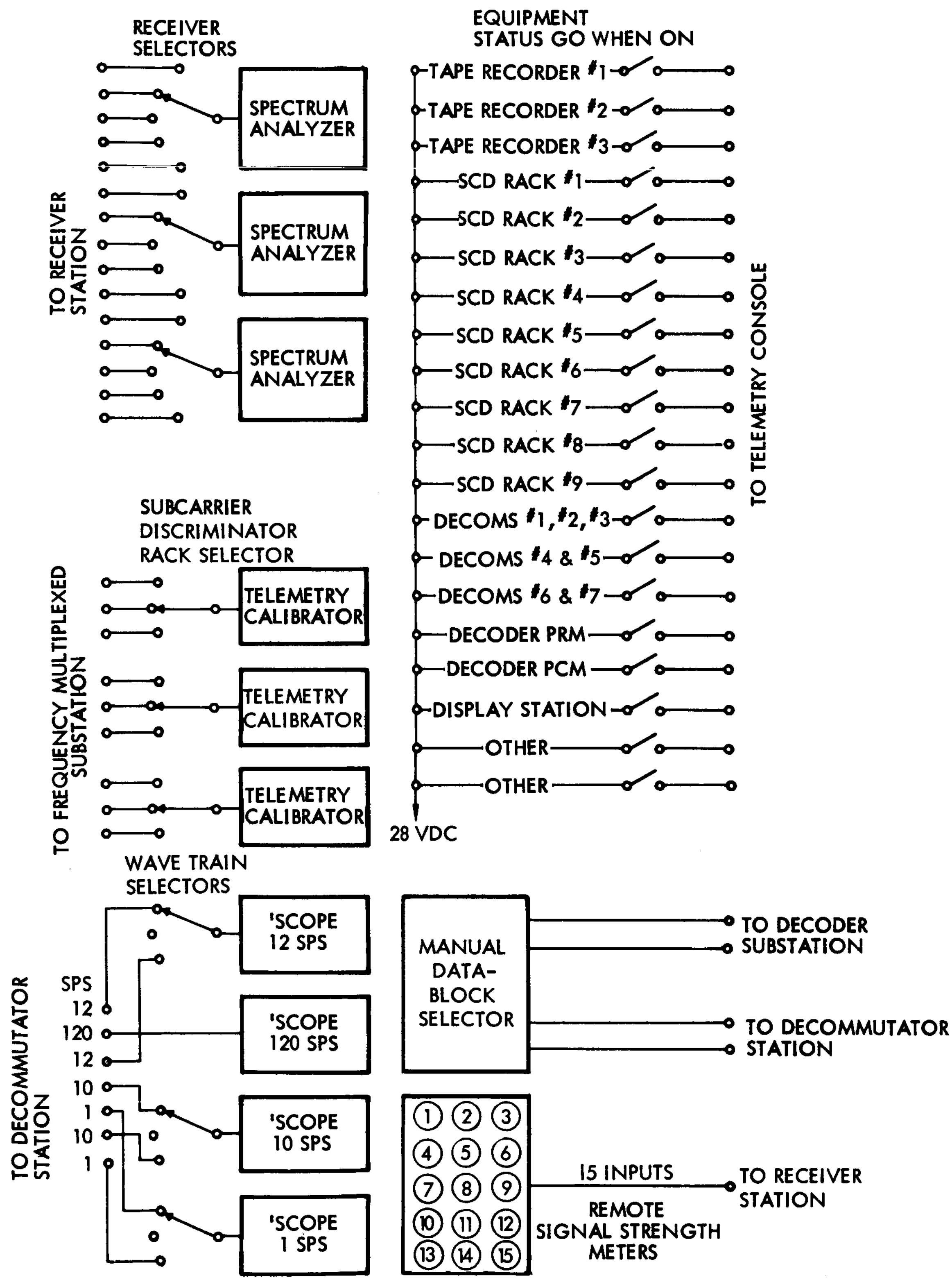

Figure 5-22. Block Diagram of Telemetry Control Station

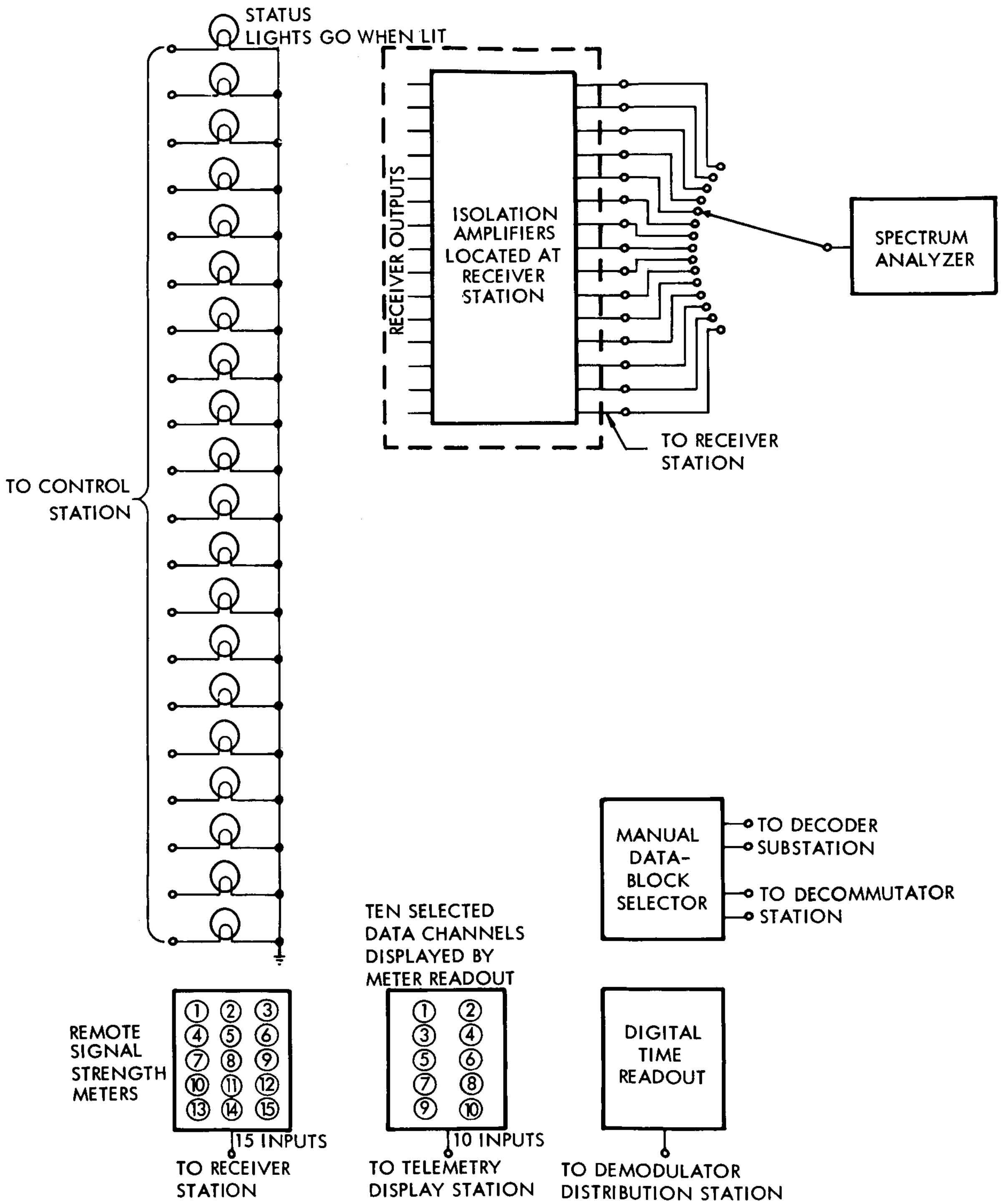

Figure 5-23. Block Diagram of Telemetry Control and Display Console

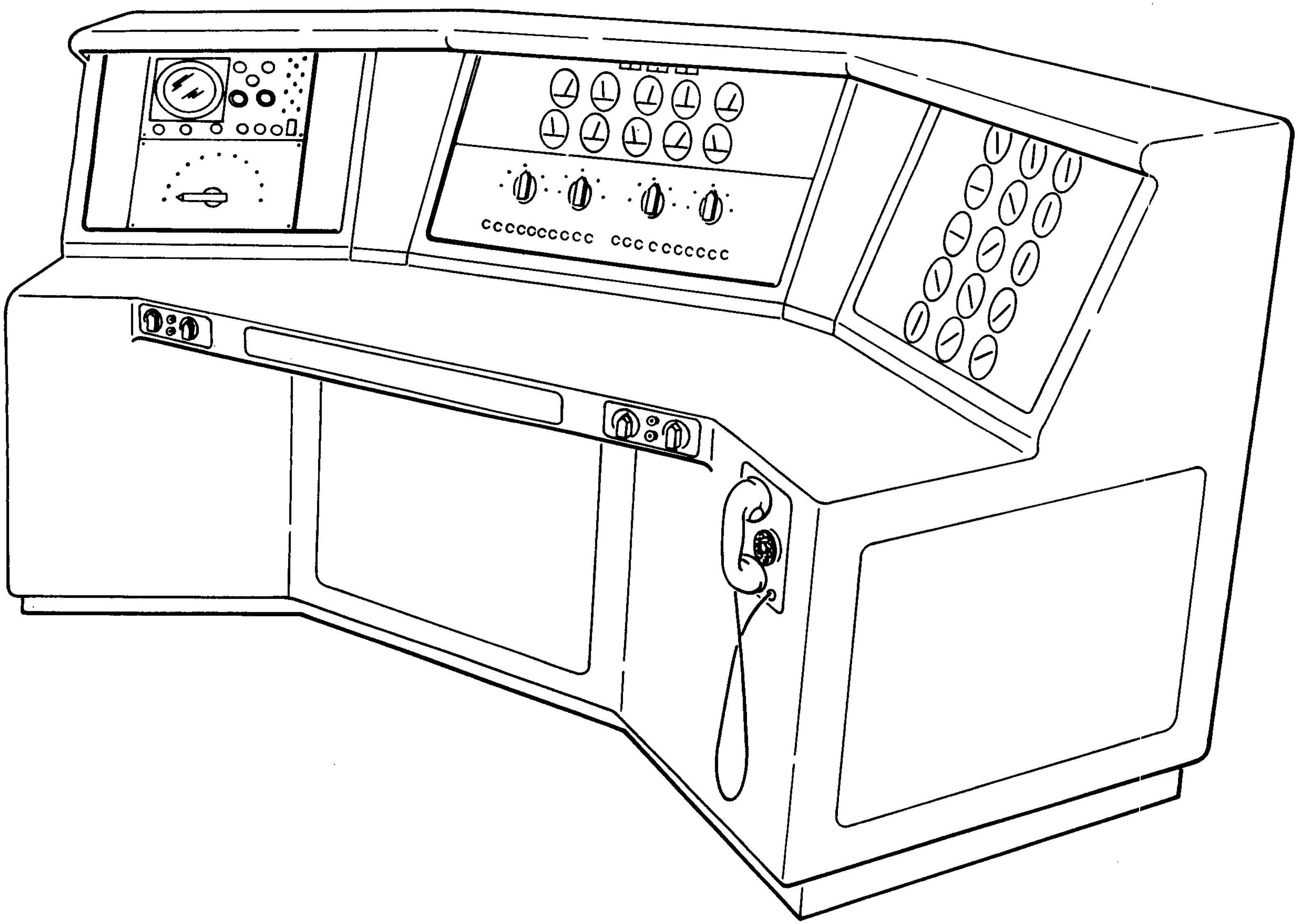

Figure 5-24. Telemetry Control and Display Console

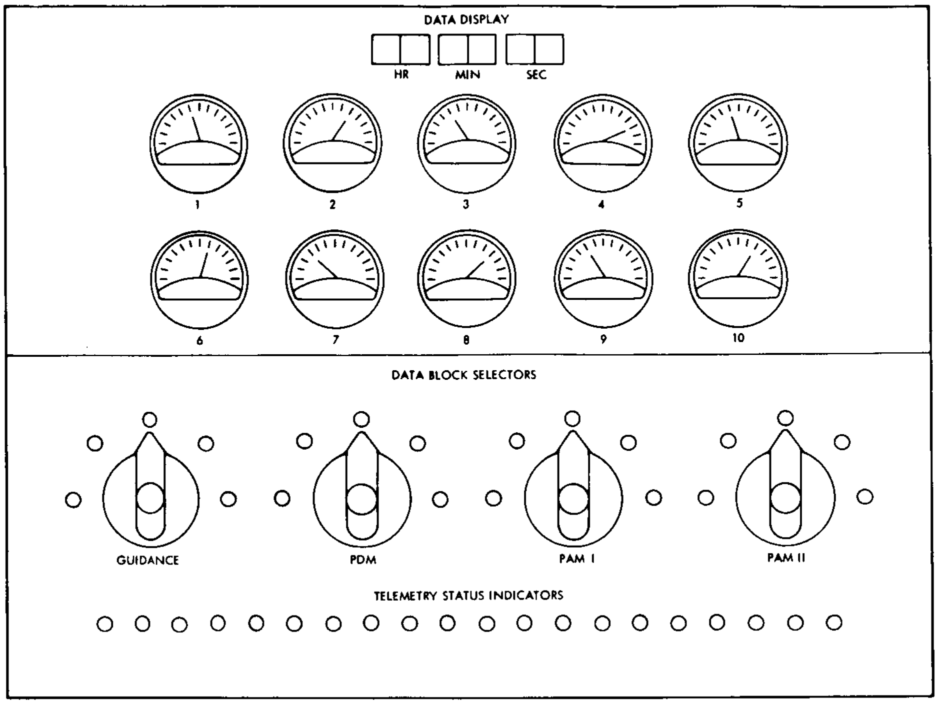

Figure 5-25. Detailed View of Data Display and Control Panel

5.3.3.2 Receiver Station

The receivers in Figure 5-16 resemble telemetry ground station receivers used in vehicle flight tests except for a lower sensitivity requirement. The received r-f carriers are either radiated or conducted through coax from the nearby launch pad. In either case, the signal level is high relative to levels encountered during flight. The coaxial cables are used when it is desired to operate the telemeters without radiating. In order to minimize coax leakage radiation, the various r-f carriers are attenuated to an appropriate level prior to transmission through the cables. Receivers 13 and 14 are spares. The output of each receiver can be fed to the tape recorder station, to the demodulator distribution station, and/or to the control station. Receivers 1 through 14 receive inputs from a multicoupler, which permits operation of all receivers from a single antenna system. Receiver 15, operating on 2200 megacycles, receives its input from a special high-frequency antenna system.

5.3.3.3 Tape Recorder Station

A block wiring diagram of the tape recorder station appears in Figure 5-17. The recorders are of the type normally used in the acquisition of telemetry data. Each recorder has seven inputs, five for telemetry data, one for voice annotation (MOPS), and one for range time and wow flutter compensation data.

In the playback mode, a test may be repeated to study an unusual occurrence or a failure. The playback mode may also be used to inject GSE test formats which artificially cause the operational computer complex to generate a "no-go" status report.

Start and stop time may be set into the range time decoder. This unit causes the recorder to run to a particular range time start and play back from thence to the stop time.

5.3.3.4 Demodulator Distribution Station

The outputs of the receiver as well as the tape recorder playback data are fed to the demodulator distribution station. In the four panels of this station, the outputs of the receivers are distributed to the appropriate processing stations. Also, proper use is made of "real time" and "playback time " and of voice annotation.

The digital data is processed in the decoder substation shown diagramatically in Figure 5-18. The guidance PCM decoder handles information generated by the vehicle guidance computer as well as by other sources in the instrumentation unit. It also telemeters 64 channels of analog data.

The developmental PCM decoder processes the serial binary data received from the vehicle development PCM telemetry system. Because this data duplicates data telemetered on one of the FM/FM links, both sets of data are fed to the operational computer complex. At some point early in the prelaunch test program, the two sets of data are compared for equality and, if found to match with preset tolerances, the computer registers a "go."

The decoder substation also processes 30 single-sideband channels. These channels carry high-frequency (3-kilocycle) vibration and acoustical data that is inherently very difficult to program for computer use. Therefore, the data is fed only to the telemetry display station. Five PDM channels derived from various subcarriers are delivered to the PDM decoders. All 315 outputs from the decoders are fed to the display station. They are also fed into a selector which, on operational computer complex command, selects one of four blocks of 50 data channels.

The telemetry ground station includes a manual command device (not shown) that simulates the computer commands in selecting a block of data on those tests where the computer is not available.

Nine racks of subcarrier discriminators comprise the frequency-multiplexed substation shown in Figure 5-19. Using the standard discriminator chassis, which can be set up on any channel by the insertion of the appropriate plug-in unit, maximum flexibility is obtained. Each discriminator rack contains one additional subcarrier discriminator as a spare.

5.3.3.5 Decommutator Station

The decommutator station shown schematically in Figure 5-20 includes seven decommutators which process the pulse-amplitude-modulated (PAM) data. These units are of the universal type that permits operation with a wide range of sampling speeds and number of segments. The sampling speeds and number of segments shown are the prime requirements. A decommutator inherently has as many outputs as there are channels being time shared on that channel. However, because of the large quantity of data this represents, selectors are used to select one of three predetermined blocks of 100 data channels by computer command. Thus, on a particular test phase the computer is only concerned with 100 channels.

5.3.3.6 Display Station

Figure 5-21 is a diagram of the telemetry display station. No effort has been made to display all data received by the telemetry station. Only that data which is of direct value in defining a "go/no-go" vehicle status is processed for the operational computer complex. To assist in improvement of the confidence factor as well as for failure analysis work, this data, as well as a number of other channels, is displayed visually either on recording paper or on an oscilloscope.

5.3.3.7 Control Station

The data presented in the display station is obtained continuously and becomes a historical record of the particular test. In the event the operational computer complex announces a "no-go" during a test and the "no-go" is based on out-of-limit telemetry data, the chief telemetry operator will make an immediate examination of the telemetry ground station via the telemetry control station. At the control station, shown in Figure 5-22, the chief telemetry operator is able to make a rapid operational status check of all stations. Because this status check is performed as a search for a possible malfunction in a variety of units, the status check is not automated. The information obtained at the control station is supplemented by visual information obtained directly from the front panel meters of the suspected units.

The control station is also used in the initial setup and calibration of the telemetry ground station prior to a vehicle test.

As seen in Figure 5-22, the operator has the facility to connect the outputs of any three receivers to spectrum analyzers. He may also feed calibration signals into each subcarrier discriminator system for a quick status check of each subcarrier discriminator in the system or for a calibration of the discriminator and associated paper recorder channel.

The demodulator distribution station is located adjacent to the control station, so that the chief operator may shift equipment in the event a unit is found to be inoperative. The controls for manual selection of data blocks in the time-shared telemetry channels are also available at the control station.

5.3.3.8 Station Crew

The chief telemetry operator is situated so that he may quickly move to a trouble area in the telemetry ground station. He is in voice communication with the other seven members of the telemetry ground station crew. These other members are assigned as follows:

a) Receiver station

b) Tape recorder station

c) Decommutator and decoder stations

d) Frequency-multiplexed station (2)

e) Display station (2).

5.3.3.9 The Telemetry Control and Display Console

Located in the blockhouse is a console (Figures 5-23 through 5-25) that provides an immediate and comprehensive display of the telemetry ground station status. A number of the displayed parameters are derived directly from the pertinent telemetry equipment and fed to the console through appropriate isolation amplifiers. Other channels are indicators only, and are normally controlled by the chief telemetry operator to provide a continuous presentation of equipment status. The console operator is in voice communication with the chief telemetry operator and, on a separate channel, with the vehicle test MOPS line.

5.3.3.10 Computer Tie-In

Once the station is set up and calibrated, the operation of the telemetry ground station is automatically controlled by the computer complex. Blocks of data are selected and measurements within the selected block are examined for in- or out-of-limit condition. The manual operation of the station comes into play when a malfunction is detected. Technically, it would be possible to automate the entire telemetry ground station operation. However, most of the units used were originally designed for manual operations, and attempts to automate this use would require essentially a major redesign.

Analog telemetry information can be sent to the computer in several forms. If the number of analog quantities into the computer is large, or if the distance between the telemetry station and the data processing complex is great, then the most efficient method of handling the data is to multiplex the signals, convert to digital, assemble the digital words into a convenient format for the computer, and use digital transmission techniques.

This has the disadvantage of requiring additional equipment which essentially duplicates the capability of the RCA 110 system. Therefore, the method considered here is to run the analog signals directly into the computer analog input channels. It is estimated that about 350 input channels would be required. The final choice of an approach is subject to the considerations mentioned above, as well as the number of analog input channels available at the computer after other system requirements have been satisfied.

The digital information sent via the PCM link will be sent directly into a computer input-output register. Words would be assembled in the computer register, and a word sync signal from the telemetry receiver would be used to gate in the information. The computer, using frame sync as an index, would then select the information it desired.

The major consideration here is the data rate involved, and an analysis must be made of the effective speed of the computer. A preliminary study has indicated that the computer will be able to keep up with the telemetry, but with very little time to spare. If this is not the case, then additional equipment must be provided to select the desired information for the computer. In the event that consecutive digital words are required from the same frame, it will be necessary to provide external buffer storage, such as a small core memory.

5.3.4 Launch Control Console

The launch control console is the operating position from which primary control of all vehicle launch operations is exercised. Beginning with SA-5, when the computer complex is installed in the blockhouse, it is desirable to enable the existing launch control console to select and control the operational sequences as programmed in the computer. This section describes that added capability.

5.3.4.1 Description

It is expected that no more than four fixed sequences are necessary to conduct the launch operations. These sequences would be performed in a sequential manner so that a previous sequence would have to be completed satisfactorily before the next sequence could begin.

Figure 5-26 shows a typical panel layout of the additional capability required of the launch control console for automating the launch sequences. The panel contains the necessary interlocks and logic for computer control of the operational launch sequences. It is assumed that the existing C-1 launch control console contains those permissive interlocks from external sources, such as pad safety, range safety, operational flight control, etc., which are required to initiate either the propellant loading or launch sequence. These interlocks would in turn enable the operational sequence select switches for the loading and launch operations. Control of the computer during those fixed sequences would then be exercised by the control switches on the auxiliary panel.

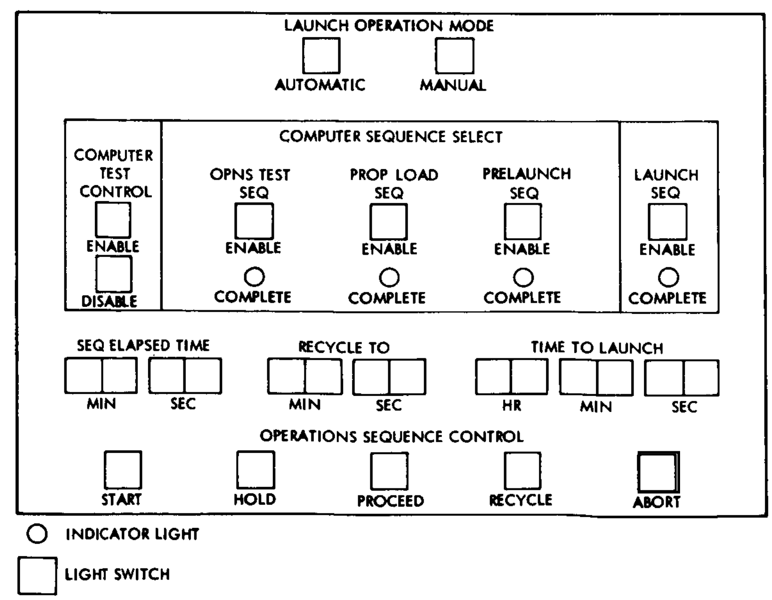

Figure 5-26. Auxiliary Launch Control Panel

For test operations, the computer control console would program all test sequences after being enabled by the launch control console auxiliary panel. Selection of either the manual- or computer-controlled automatic mode of operation is made by the mode select switches on the auxiliary panel. Once test operations have been completed, control of the computer during the fixed operational sequences is maintained at the launch control console with the auxiliary panel. Typical functions contained in the operational sequences are shown in Table 5-1.

The propellant loading sequence is controlled from the launch control console and is described in Section 5.3.5 All information as to the status of the loading operation is contained on the propellant loading console which is adjacent to the launch control console. For operational control, the computer control console, the propellant loading console, and the launch control console give complete information and control for all operations necessary for the final checkout and launch of the Saturn vehicle.

The computer program contains the necessary instructions to maintain a safe condition in case of a "hold" condition, as well as for recycling in any particular sequence. As part of the final launch operations sequence, appropriate instructions are given for returning the facility to a safe condition after launch of the vehicle, or returning the vehicle and facility to a safe condition in case of an aborted launch sequence (e.g., return from arm to safe, transfer to external power, transfer to external pressurization, drain propellant tanks, etc.).

5.3.4.2 Computer Tie-In

In the automatic launch mode, the operation of the computer may be broken into three phases. Phase 1 is the test operation prior to the actual launch procedure. During this phase, the computer carries out test operations with a relatively free hand. Phase 2 begins at about T minus one day. Now the computer control is enabled from the launch control console. During this phase, the computer considers the relative priority of the tasks presented to it. Phase 3 commences upon the satisfactory completion of test operations. It is interesting to note that the old program

Table 5-1. Typical Functions During Launch Operational Sequences

Operational Test	Propellant Loading	Prelaunch	Launch
Instrumentation Calibration	Typical sequence described in Section 5.3.5	Activate Batteries	Stop Propellant Topping
Pressure Transducer Check Program		Check Critical Pressure Switches (Abort System)	Arm Ordnance
Facility Preparations Check for Propellant Loading		Facility Summary Check	Transfer to Internal Power
Vehicle Preparations Check for Propellant Loading		Missile Summary Check	Transfer to Internal Pressurization
Calibrate Propellant Loading Transducers		Guidance and Control Summary Check	Engine Start Sequence
		Check Battery Activation	Check for Proper Engine Start
		Flight Pressurization	Return Facilities to Safe Condition
		Check for Correct Propellant Levels	

priority relationship is no longer strictly valid; from now on, the command and resulting program last given by the launch control console must have highest priority.

Figure 5-27 illustrates the launch control console interface with the computer program. It begins with the computer in an interruptible self-checking loop. A computer failure in this loop will be reported to the launch control console by means of the hold indicator. The launch control console may then enable the computer control maintenance. If all is well with the computer, however, the launch control console may start the launch operations, which results in a start interrupt. This interrupt is interlocked so that it can occur only once. This is done to avoid any sideways entrance into the programs, which must be executed in a series, beginning with test operations. The launch control console enables each phase of the total program manually, and the program interlocks are also provided so that a program cannot be entered unless enabled by the launch control console.

Upon completion of each of the primary programs, the computer goes into the corresponding "hold" program. The "hold" program maintains status quo in the vehicle, and a normal entry into the "hold" program indicates successful completion to the launch control console. If the "hold" program is entered by any other means, the launch control console hold indicator is activated. In this case, the "hold" program may automatically cause a minor "cycle down" to avoid a dangerous commission. The launch control console may order a recycle through that program and can order a complete scrub or "cycle down" at any time. Upon successful completion of a program, the launch control console may then enable the next program in order of proceed.

Figure 5-28 illustrates in greater detail the launch control console interface with the computer programs. The program interlock checks to see that this program is entered by a normal "hold" condition. It also checks to see that the proper program is loaded and verified, and that program identification agrees with the launch control console system's enable.

This program interlock backs up electromechanical interlocks on the

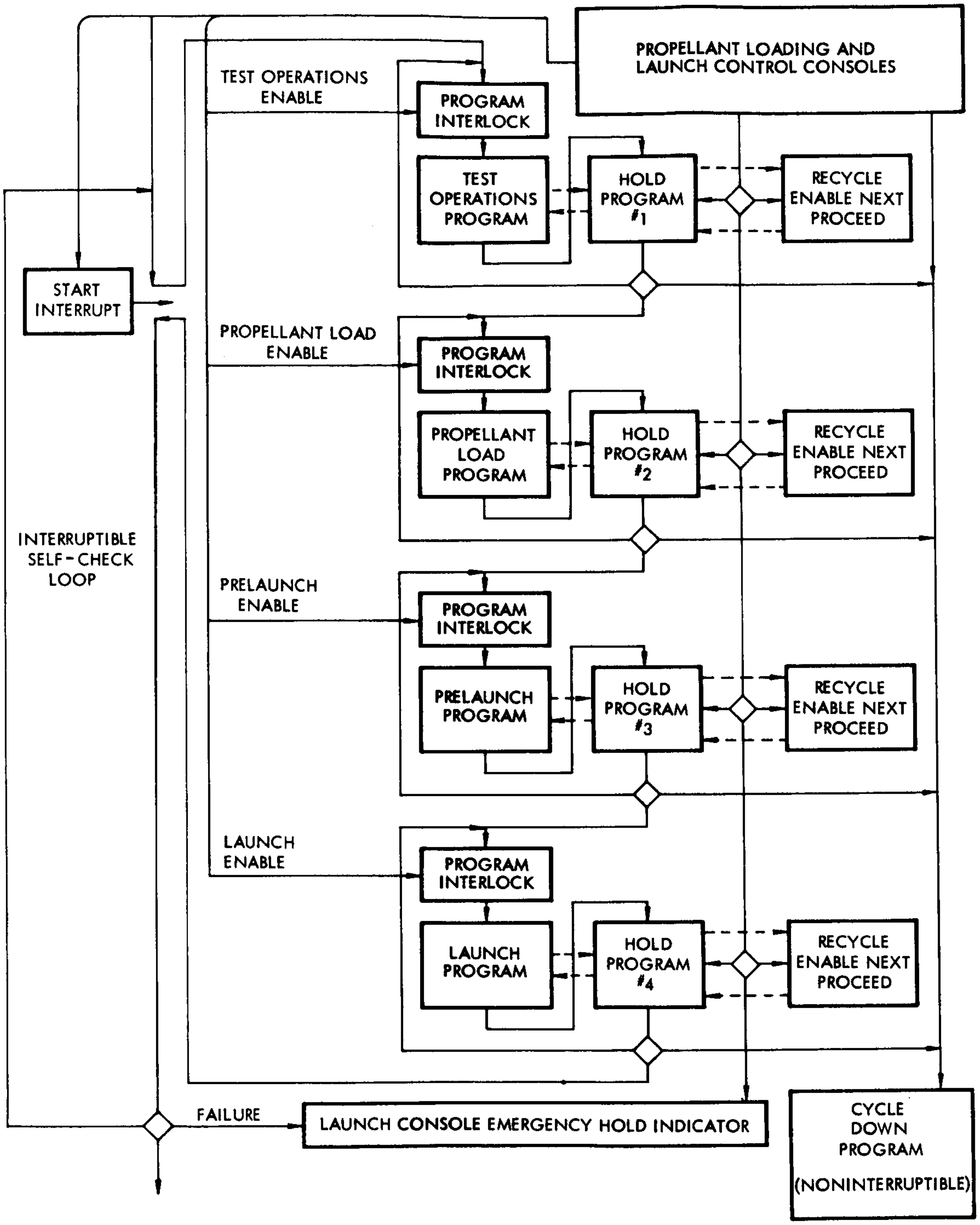

Figure 5-27. Block Diagram of Launch Control Console - Computer Program Interface

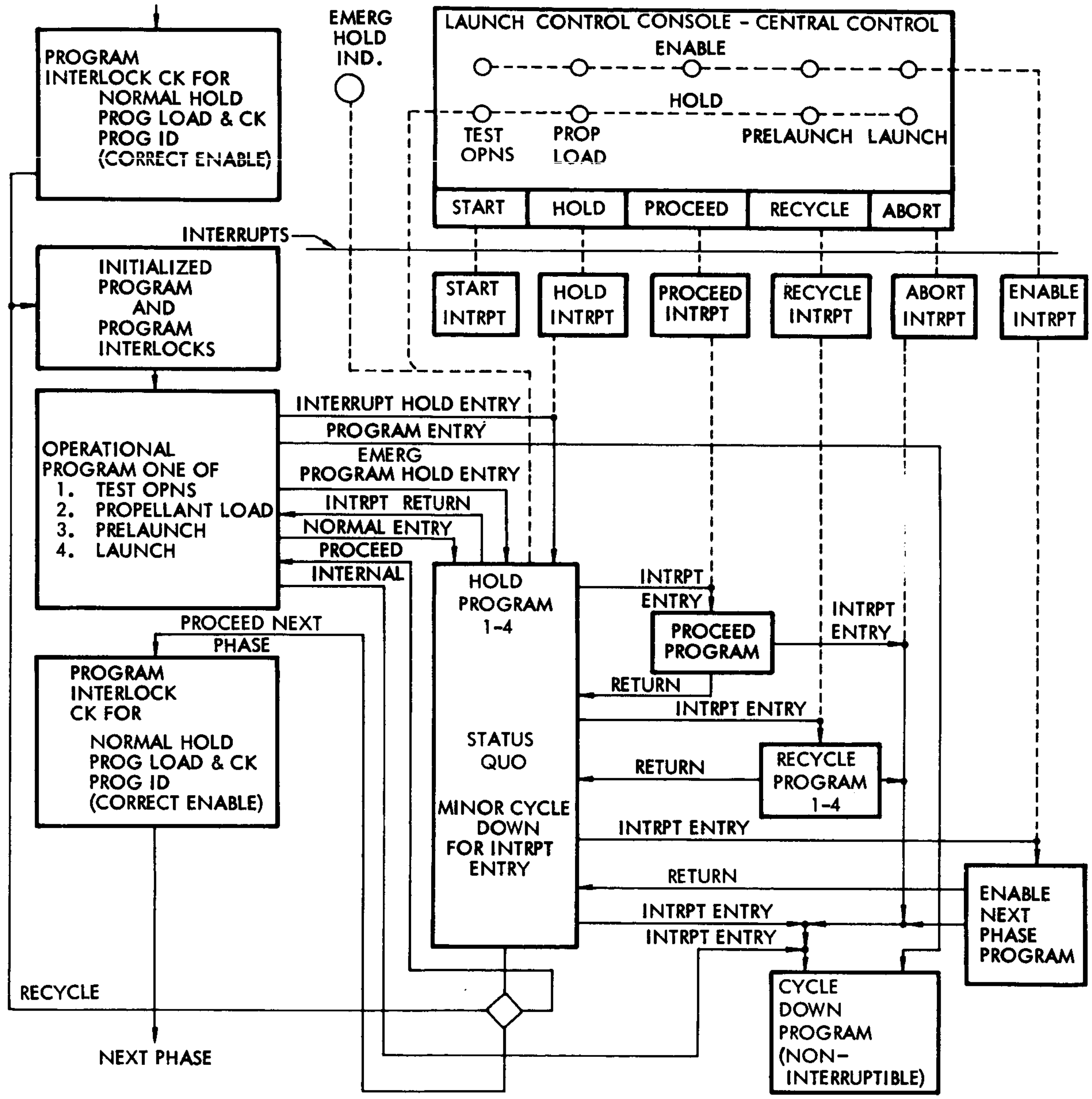

Figure 5-28. Detail Section, Launch Control Console - Computer Program Interface

launch control console. Now the computer starts the program and sets the exit program interlock.

The "hold" program may be entered in three ways. First, the launch control console may command entry into the "hold" program by means of interrupt at any time during the execution of an operational program. Confirmation appears on the hold indicator. A command by the launch control console to proceed will cause re-entry to the operational program at the point of interrupt, via the interrupt return. The operational program itself may enter the "hold" program on discovery of an emergency condition. The launch control console is again notified via the "hold" indicator. Again, the launch control console may command a proceed, and now the operational program is re-entered by an internal proceed. Finally, the "hold" program is entered by the normal entry upon successful completion of the program.

Further program interlocks are provided that also back up the interlocks on the launch control console. Interrupt is turned on and off the "proceed" program only in the "hold" programs, so that proceed has no effect unless the program is on hold. Proceed can mean one of two things. In a normal "hold" condition, proceed means go to the next phase. If the "hold" program was entered by an interrupt, or by the emergency program hold, proceed means to continue the current operational program. Proceed is interlocked so that it never causes recycle in itself. Interrupt controls for the "recycle" program are also in the "hold" program, so that recycle cannot occur unless a "hold" condition exists.

The same remarks apply to the "enable next phase" program. The "cycle down" program, entered by means of an abort interrupt, has no interlock conditions. This program may be activated by the launch control console at any time with instant compliance. It may also be computer activated. Once the program is entered, it will run to completion and it will be noninterruptible.

Figure 5-29 illustrates the computer drive and control for the launch control console. The commands and enables given by the launch control console generate separate interrupts to the computer via the discrete input

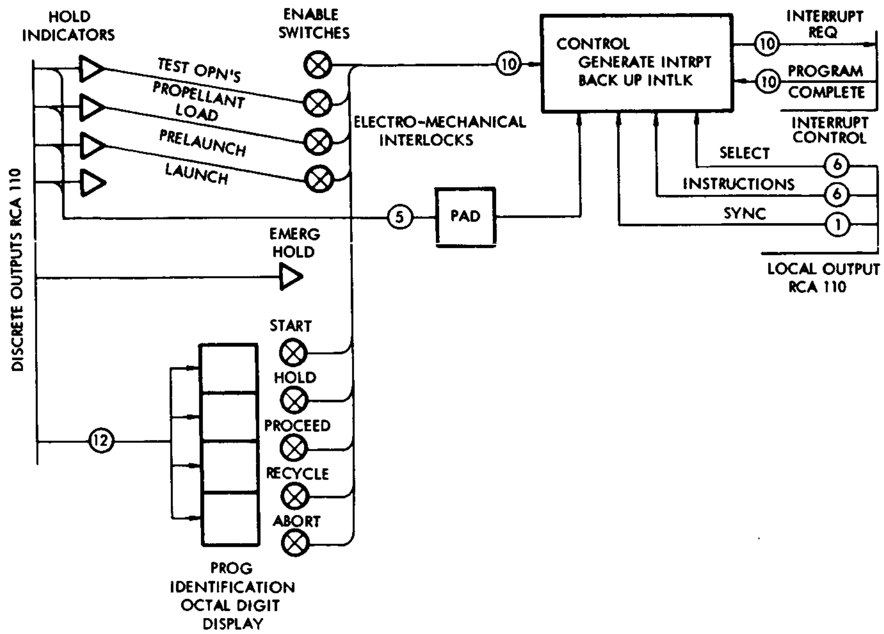

Figure 5-29. Block Diagram of Launch Control Console Computer Drive and Control

lines. The control for the computer drive requires extensive interlocking. Information back from the computer to the launch control console "hold" indicator are fed into this control on the discrete output lines. The launch control commands (which are interrupts) are also fed into this control. All the systems operational interlocks should be backed up with redundant logic. Thus, there is a complete set of program interlocks, electronic and electromechanical, for these critical control functions.

5.3.5 Propellant Loading Console

Because the transfer of propellants to the vehicle is hazardous, this operation should have special displays for monitoring and emergency control. Design consideration must be given to the type of sensors installed in the vehicle and facility. The sensor must furnish the computer program and operator with the necessary information on which to base a minimum time, accurate loading sequence, and rapid backout capability at any time after loading starts. Since a component failure could cause a dangerous condition, redundancy of information available either by the data link or airborne instrumentation system should be utilized. The automation of propellant loading may therefore require that additional sensors and instrumentation be installed for use with the computer program and the propellant loading console.

As with the launch control console, it is necessary to provide a capability for automation of the propellant loading, beginning with SA-5. This following section describes that added capability.

5.3.5.1 Description

It is recommended that a propellant loading display console, in addition to the existing manually operated propellant loading console, be added to the C-1 complex for use with the computer during the initial automation effort. This display console would receive its information from the computer and contain the displays necessary to determine the status of propellant loading being conducted by the computer. A typical layout of this console is shown in Figure 5-30.

Since a manual capability for propellant loading does exist along with its display, the only emergency control that is desirable on this additional display console is a means of disconnecting the computer program so that necessary action can be taken with the existing propellant loading console without interference from the computer. A typical automated loading sequence is shown in Table 5-2.

The display is predicated upon a delta pressure loading system, so that the level of each tank can be ascertained at any time. When the propellant in the tanks reaches predetermined levels, the delta pressure indication causes the rapid load valve to shut so that final loading takes place under fine load conditions. Final propellant levels can be controlled by either a partial delta pressure transducer or point sensors of the required accuracy.

In addition to displaying propellant loading status, this console also displays the status of the pressurization system of both the vehicle and facility storage tanks. The basic assumption has been made that the airborne pressurization storage tanks will be located within one of the

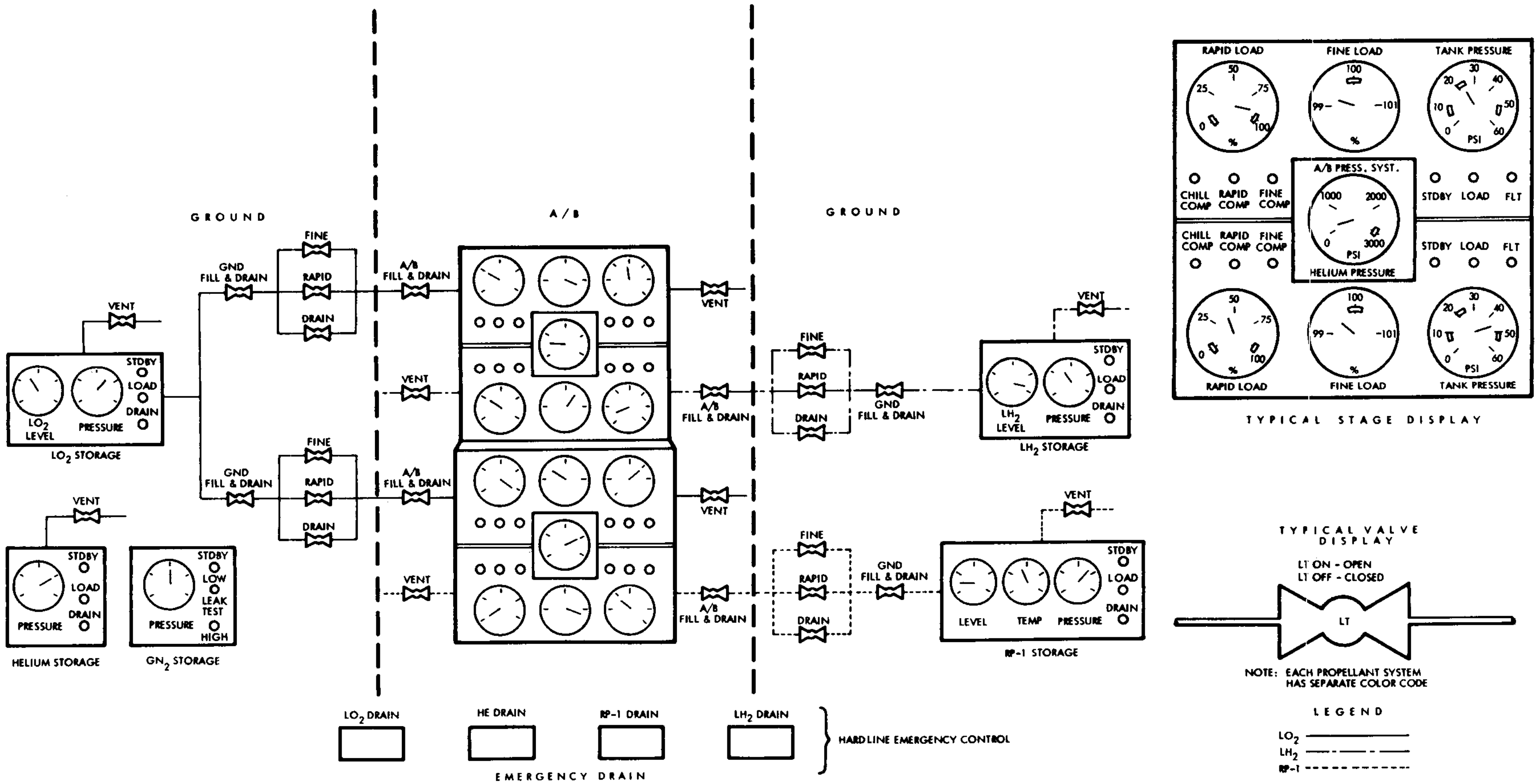

Figure 5-30. Schematic Diagram of Propellant Loading Console

Table 5-2. Typical Automated Loading Sequence

Location	Action	Initiated By
Computer FAC and VEH	Initiate Operational Loading Sequence Pressurize Storage and Vehicle Tanks to Loading Pressures	Launch Opens Console
1st	Start Transfer of RP-1	Proper Loading Pressure
1st	Start LO_2 Chilldown	
1st	Start LO_2 Rapid Load	LO_2 at 5% Level
2nd	Start LO_2 Chilldown Start LH_2 Chilldown	Proper Pressure and 1st Stage Rapid Load Start plus ____ seconds
2nd	Start LO_2 Rapid Load	LO_2 at 5% Level
	Start LH_2 Rapid Load	LH_2 at 5% Level
1st	Start Helium Load	LO_2 at 25% Level
2nd	Start Helium Load	LO_2 at 25% Level
1st	Stop RP-1 Rapid Load	RP_1 at 90-95% Level
1st	Stop RP-1 Rapid Load	RP_1 at 100% Level
1st	Stop LO_2 Rapid Load	LO_2 at 90-95% Level
2nd	Stop LO_2 Rapid Load	LO_2 at 90-95% Level
2nd	Stop LH_2 Rapid Load	LH_2 at 90-95% Level
1st	Stop LO_2 Fine Load	LO_2 at 100% Level
1st	Stop Helium Load	Helium at 3000 psi
2nd	Stop LO_2 Fine Load	LO_2 at 100% Level
2nd	Stop LH_2 Fine Load	LH_2 at 100% Level
2nd	Stop Helium Load	Helium at 3000 psi
VEH	Propellant Loading Complete	Launch Opens Console

NOTE: 1) All tanks will continue to top through the fine load valve around predetermined limits, i.e., 99.8% to 100.2% until final launch operations sequence is initiated.
2) Additional functions required but not shown, i.e., start transfer pumps, etc.
3) Checkout and calibration of a propellant utilization system could be accomplished during the loading sequence if such systems are utilized by any of the stages.
4) If concurrent propellant loading is not permissible, then sequential loading could be accomplished in a similar manner.

cryogenic propellant tanks so that additional chilldown will not be necessary. Should this not be the case, displays for a liquid nitrogen chilldown system and helium temperature measurements could be added. Loading of the pressurization system would occur under computer control as part of the propellant loading sequence. The computer program will be able to recognize emergency conditions and will be so programmed to take the necessary action to return the vehicle to a safe condition.

5.3.5.2 Computer Tie-In

The propellant loading console is, as far as the computer is concerned, primarily a display. The controls are direct hardlines, and are sensed by the computer "for information only."

The indicator lights are driven directly by the discrete lines. The dial indicators shown are analog meters, each driven by a simple resistor network from a digital register. In-line decimal readouts could be used, but the circular dials may offer some advantages from a human factors point of view.

5.3.6 Data Recording

The computer is equipped with magnetic and paper tape facilities and a typewriter. These serve as the input-output and recording media for the benefit of the human operator and for later evaluation. Electric typewriter outputs at the rate of 10 characters per second, and two paper tape punches and readers communicate with the computer at the rate of 60 characters per second.

The drum memory has a satisfactory bulk storage for programs and for blocks of intermediate results from the high-speed store. However, it is desirable to add magnetic tape stations for the following reasons:

a) A permanent record of the operation should be made to preserve the raw data, test results, and control data.

b) This media is physically compatible in format for further extensive processing in the data reduction center.

Up to 10 magnetic tape stations may be added to the computer. These communicate with the computer at the rate of 30,000 characters per second. The computer is organized so that input-output operations may proceed in parallel with the arithmetic operations to a limited extent.

As an example of usage, one tape might be assigned as a log tape. On this tape would be recorded the record number, test number, month and day, test point number, measured value, high limit, low limit, value of stimulus applied, time, etc. These items would be repeated for each test point, as required. On another tape, a record might be kept of those test points which have failures. Essentially the same information would be recorded as in the preceding, but only for the failure points. Still another tape might be used to preserve raw data, such as PCM data entering the computer and digitized analog outputs from the telemetry system.

It is assumed that during the installation, checkout, and early flight tests, additional data recording equipment will be added for debugging and troubleshooting purposes.

6. C-5 VEHICLE GROUND SUPPORT EQUIPMENT

This section presents a description of an automation system for the C-5 vehicle. The system represents a direct extension of the general approach and hardware described in the previous section for the C-1 system. As before, the overall design is based on a general concept developed by MSFC with further definition of system and hardware requirements.

6.1 General Concept

A special assembly building is provided for the C-5 vehicle as shown in the MSFC drawing, Figure 6-1. Upper stages, including the spacecraft, are first brought to the stage checkout area where they are qualified as individual stages. The stages are then vertically assembled into total vehicles on transporters in a vertical assembly area. Each transporter has its own set of GSE which is capable of a complete and independent operational checkout of the vehicle system. Measuring and telemetry checkout can also be accomplished in conjunction with the central instrumentation and measuring facility. At about one week prior to launch, a transporter with its checkout vehicle and GSE system will be moved along a rail system to take its firing position on one of the two launching pads. Along the way, the vehicle receives ordnance installation, high pressure checks, etc. Upon reaching the pad the vehicle system is connected to propellant loading facilities similar in nature to those used in the remote operation of Complex 37. Checkout of the vehicle system can resume just as it did in the vertical assembly facility since the transporter and its GSE are capable of independent operation. The central instrumentation and measuring facility can continue to monitor all telemetry outputs through the r-f link or over a closed coaxial connection.

At a time when the entire launch operation is simulated, such as simulated flight test, the GSE is tied through a communications link to an operational computer located in the vertical assembly facility. All operations of the vehicle system can now be handled remotely through this data link. Data coming from the vehicle system is transmitted to a launch control room in the vertical assembly facility. Vehicle system information can be sent to the operational flight control center and compared with central instrumentation and measuring facility data. A command to the vehicle system is received from operational flight control or the launch control room and transmitted via the communications link back to the transporter GSE, which in turn causes this command to be carried out. On launch day, the system operates in the same manner with the central instrumentation and measuring facility and operational flight control continuing to monitor and control the vehicle after liftoff.

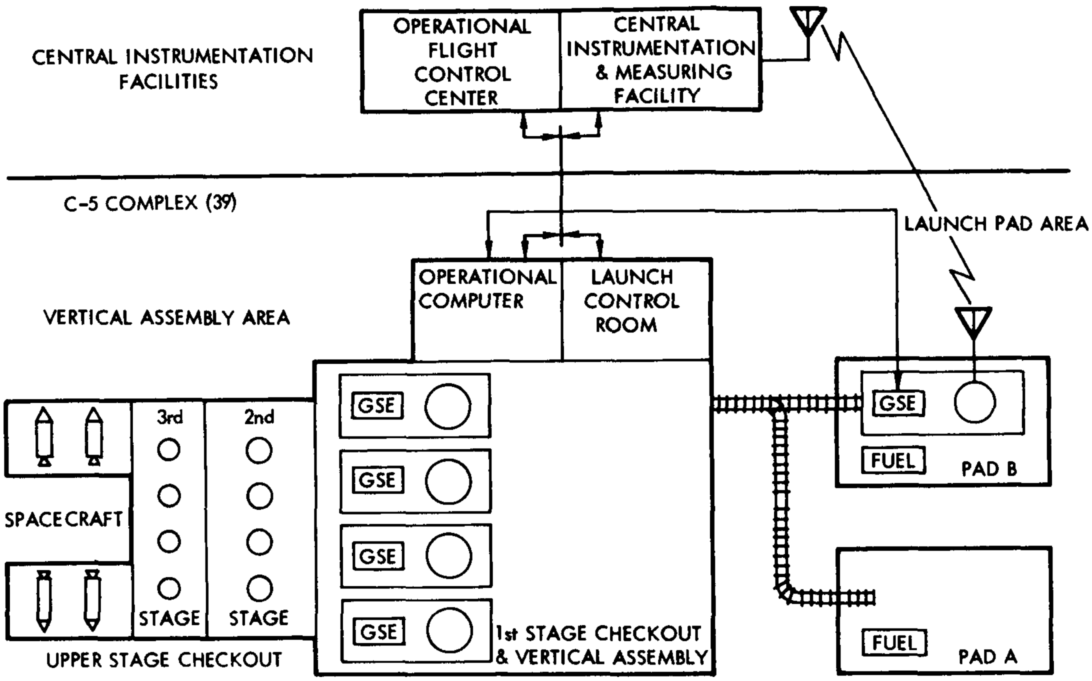

Figure 6-1. C-5 Operations Plan

6.2 The C-5 Automation System

A block diagram showing the general layout of automation equipment for the C-5 system is presented in Figure 6-2. The computer complex and computer control and display console shown in the transporter are essentially the same as used previously with the C-1 vehicle. New items of equipment are the vehicle, Apollo GSE, analyst displays, and the data link equipment.

The Apollo GSE is shown located on the transporter because of the anticipated requirement for many hardline connections to the spacecraft. It is assumed that there will be some control of this GSE by the computer complex, but details of the interface will require much additional work and close coordination between the divisions of NASA involved. Although

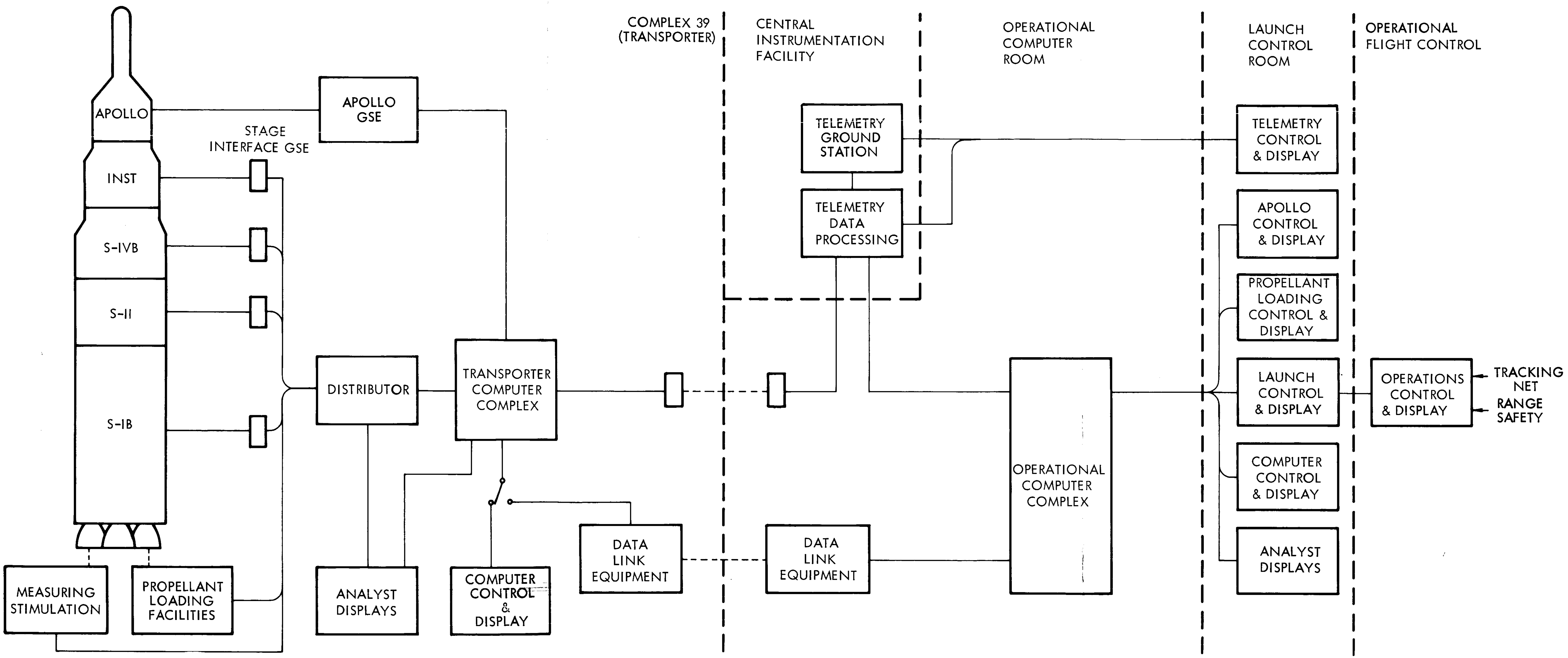

Figure 6-2. Automation System Configuration for Saturn C-5 Vehicle

not shown, a special data link may be required between the Apollo GSE on the transporter and the Apollo control and display equipment back at the launch control room.

The analyst displays on the transporter represent a logical extension of the display capability provided by manual operating positions for the C-1 system. The purpose of these consoles is to provide a trained specialist with sufficient information to monitor intelligently performance of his subsystem or stage during the various test and launch operations. A primary source of information for the displays is the computer, which programs digital data to the consoles on a selective bases. A secondary and less extensive source of information is analog data from hardline connections to the vehicle. Use of these consoles relieves the computer operator of much routine monitoring responsibilities and provides valuable assistance during troubleshooting operations.

A second set of analyst consoles is located in the launch control room to support the remote launch operation. These consoles are essentially identical to those located on the transporter, except that analog display information is eliminated. Because of bandwidth limitations associated with the data link, the operational computer complex obtains very little detailed test information from the transporter except by special request. Therefore, the digital data supplied to the analyst displays from the operational computer is derived in large part from telemetry sources.

The computer control and display console located in the launch control room is essentially identical to the one located in the transporter, and to the one described for the C-1 complex. Likewise, the propellant loading console is similar to the one used for the C-1 vehicle except for an expanded capability to handle the added propulsion stage. The launch control console performs the same function as for the C-1 application, except for elimination of the requirement to operate with manual test consoles. The telemetry control and display console are an extended version of the C-1 unit, with an expanded PCM capability.

The general objective throughout the C-3 test and launch operation is to make maximum use of telemetry data. When the transporter is located at the assembly area, telemetry data is cabled directly to the computer complex on the transporter for test evaluation. When the transporter is moved to the pad area, the distance is too great for easy transmission of the PCM telemetry data without use of a special wideband data link. For purposes of this study, it was assumed that such a link would not be available and that only hardline data would be available at the pad. However, telemetry data is always available at the operational computer complex and can be evaluated during the remote launch operation. This approach has one distinct disadvantage insofar as the lack of telemetry data would require a change of the test program when the transporter has moved to the pad. To facilitate use of the same test program, it may be desirable to provide either a wideband data link from the control instrumentation facility or, alternately, a special telemetry ground station at the pad areas.

6.3 Description of Automation Equipment

This section outlines the equipment involved in the automation of the C-5 launch complex as shown in Figure 6-2. The transporter and operational computer complexes, the data link between them, the telemetry ground station, and the various control and display consoles are described. In most cases, there is really nothing new in the C-5 launch complex. Techniques and equipment developed in the C-1 system are directly applicable.

6.3.1 Transporter Computer Complex

6.3.1.1 Computer Description

The computer used in the transporter complex is the RCA 110 and is essentially identical to the C-1 computer configuration described in Section 5.3.1. The primary difference between the systems is that manual test consoles are replaced by system analyst display consoles driven directly by the computer, and that a data link is added to the system.

6.3.1.2 Computer Control and Display Console

In spite of the additional complexity of the C-5 vehicle systems, the nature of the control problem is the same as that of C-1. The computer control and display console is therefore identical to that described in Section 5.3.2.

6.3.1.3 Analyst Displays

6.3.1.3.1 Description

In order to increase the confidence of the operating personnel in the use of the computer for automatic checkout, prelaunch preparation, and launch support of the vehicle, it is recommended that several system analyst displays be provided. These displays utilize telemetry and hardline vehicle measurement data as well as computer-generated data to provide monitoring information for system personnel as to the condition of the vehicle, progress of tests, status of measurements, etc. The objective of each display is to provide information in easily readable system nomenclature in keeping with the principle that the analyst is completely informed about his system and its testing and need not be interested in the computer mechanization of the test or his console.

One of these displays is provided for each major functional system or stage, as appropriate. Displays are added incrementally as stages are added to the vehicle. In this way, new stages, new systems, and new measurement monitoring can be accommodated as required.

Figures 6-3 and 6-4 show a recommended configuration for such a console for a typical electromechanical system. The left side is devoted to a combination of displays to inform the operator of which test is being performed. Number, sequence, and step are given at the top, while illuminated nameplates beneath identify the test, sequence, and step. The nameplates are easily changed. By merely reprogramming the computer and inserting a new wired patchboard in the back of the console, it is possible to change the displayed information and nomenclature. The right side displays the measurement information. At the top, the identification of the measurement appears as a number while the name and value are shown immediately beneath. Two kinds of displays are used for this purpose. One is a continuous display of certain parameters while the other is a sequential display of the value of different parameters while their nameplates are illuminated. These measurements may also be changed as described above. The test status display informs the operator of the computer determined status of the test ("go," "no-go," and complete"). The lower right display

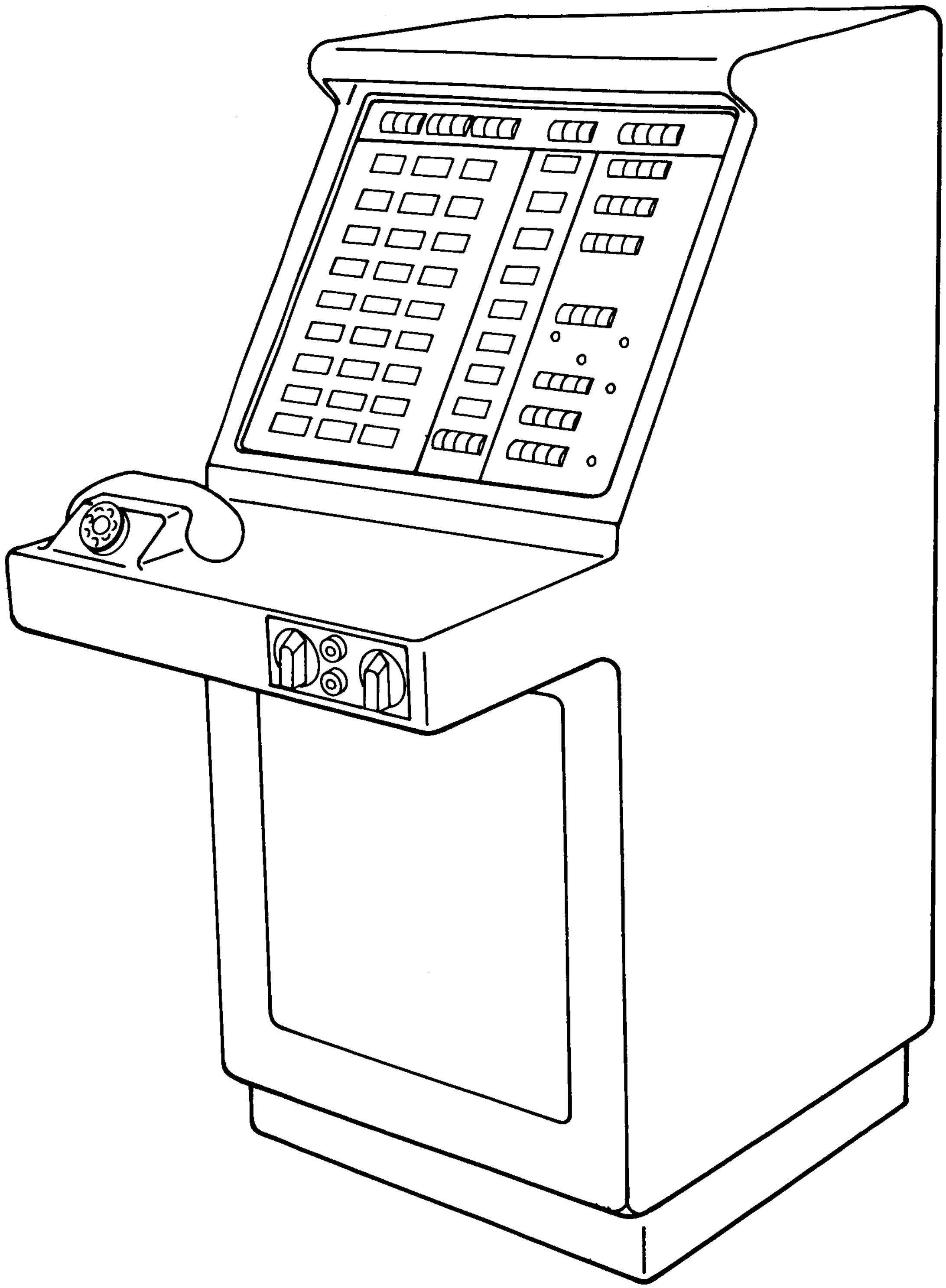

Figure 6-3. Analyst Console

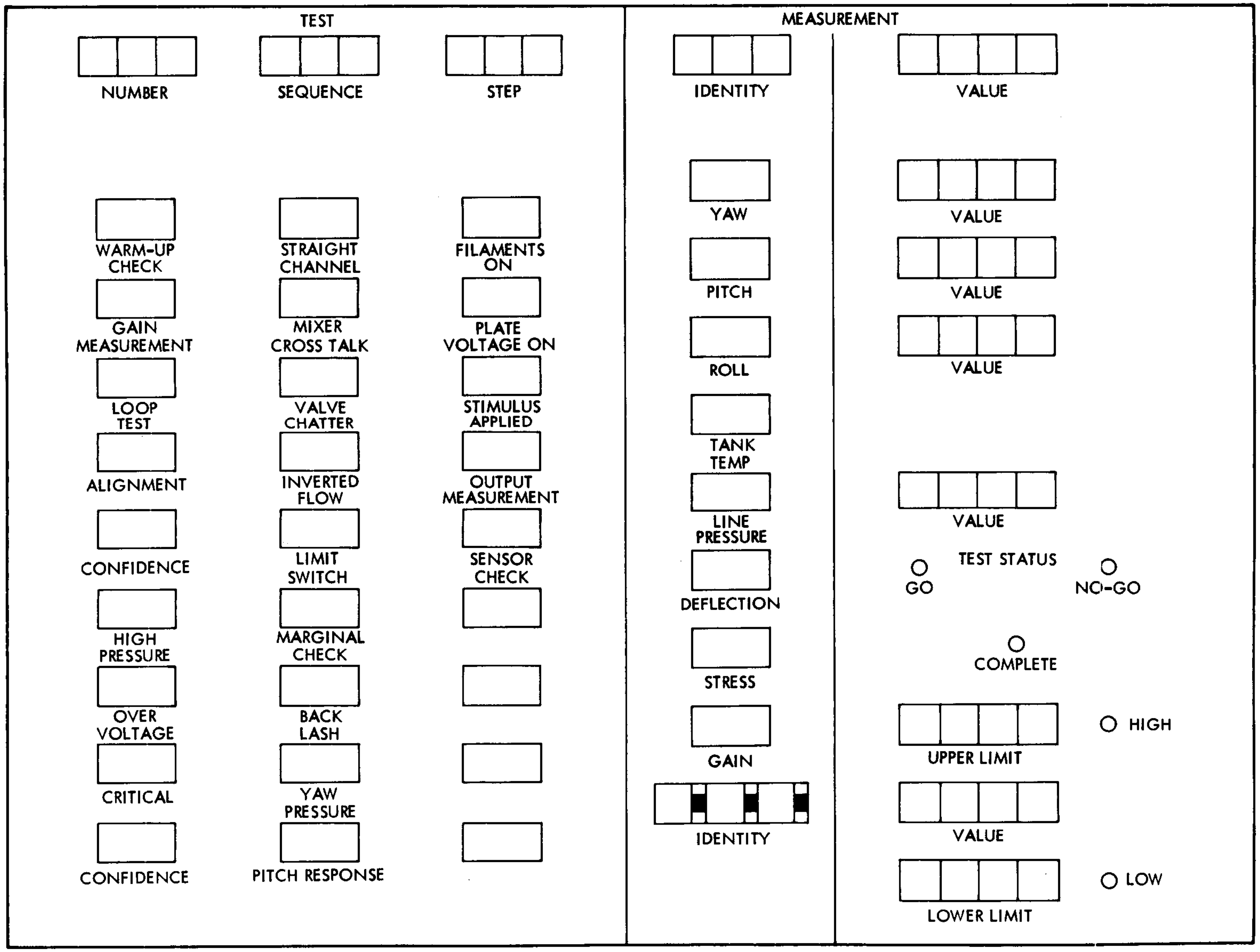

Figure 6-4. Analyst Console Panel

allows the operator to select any measurement he desires to monitor and have it displayed, together with its upper and lower limits.

6.3.1.3.2 Computer Tie-In

A primary requirement of the analyst display is flexibility. For this reason, a combination of programming and changeable plugboard techniques have been employed.

Information words from the computer contain an identification code as well as display data. This code is handled in one of two ways by the console, as shown in Figure 6-5. Some of the display registers are activated by a fixed decoding matrix, which looks at the incoming identification code. These registers must therefore be directly addressed by the computer. (Information to one of these registers is requested by a digiswitch, which is periodically scanned by the computer.)

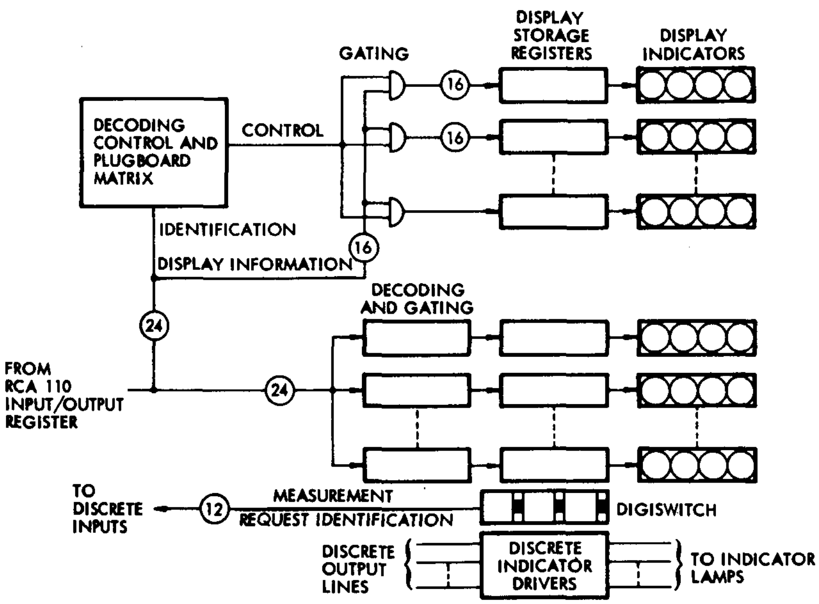

Figure 6-5. Analyst Display — Computer Tie-In

The other registers select information using a decoding matrix, which is controlled by a changeable plugboard in the console. This allows the console to display a wide variety of information without requiring program changes.

6.3.2 Operational Computer Complex

6.3.2.1 Computer Description

The RCA 110 used here is again the same basic configuration as that of C-1. However, the major source of data for the operational computer is from telemetry and from the transporter computer via the data link, rather than from hardlines. This fact, plus the greater emphasis on digital telemetry, results in a different balance between the numbers of analog and digital input channels required.

6.3.2.2 Computer Control and Display Console

The control display system described in Section 5.3.2 for the C-1 complex is directly applicable to the C-5 system. The only change required is that due to the multiple, master-slave computer system. However, a display similar to that shown in Figure 5-1 (without the Typotron) would be added to the operational computer console to indicate the detailed status of the transporter computer. It would, of course, be driven by the operational computers.

6.3.2.3 Analyst Displays

The analyst displays and their computer tie-in for the operational complex are identical to those described in Section 6.3.1.3 for the transporter complex. The difference between the two complexes lie in the sources of data for these displays; in the transporter complex, the information can be obtained from hardlines, while in the operational complex all information must come primarily from the telemetry or by special request over the data link.

6.3.3 Data Link

The C-5 system differs from the C-1 in an important aspect: the problem of computer-to-computer communications, in which one computer acts as the master and the other the slave, has been added. The process by means of which the computers talk to each other via the data link must be defined. Again, the key feature is the program interrupt. Each of the computers considers the other to be merely another input-output device — a device which can interrupt only when permission has been given through program instructions.

The slave computer grants permission for the master computer to interrupt. From then on, the master will initiate all communications. The master transmits a message to the slave, indicating that another message is to follow. The slave acknowledges receipt of this first message. The master computer then transmits an instruction message to the slave. This message specifies the task to be done. On completion of the task, the slave notifies the master of the completion and transfers results as required. Every transmission in this communication requires an interrupt.

Figure 6-6 illustrates the mechanism for computer-to-computer communications under an interrupt control. Note that the control at either end of the data link is capable of generating two kinds of interrupt, one for read and another for transmit. Manual controls should be provided to enable a step-by-step interrupt mode of operation for use in equipment checkout.

6.3.4 Telemetry Ground Station

6.3.4.1 Requirements

The telemetry ground station for the C-5 system must provide data for computer use in two different circumstances. The first is the transporter computer when it is in the vertical assembly facility. The second is the operational computer when the transporter is on the launch pad. Because the airborne telemetry systems are as yet undefined, it was necessary to make several assumptions in order to consider the ground station as a part of the launch complex.

6.3.4.2 Quantities

The number of telemetry systems to be used establishes only quantities of types of equipment in the ground station. Therefore, this factor is not important at this time and was discounted for purposes of the study.

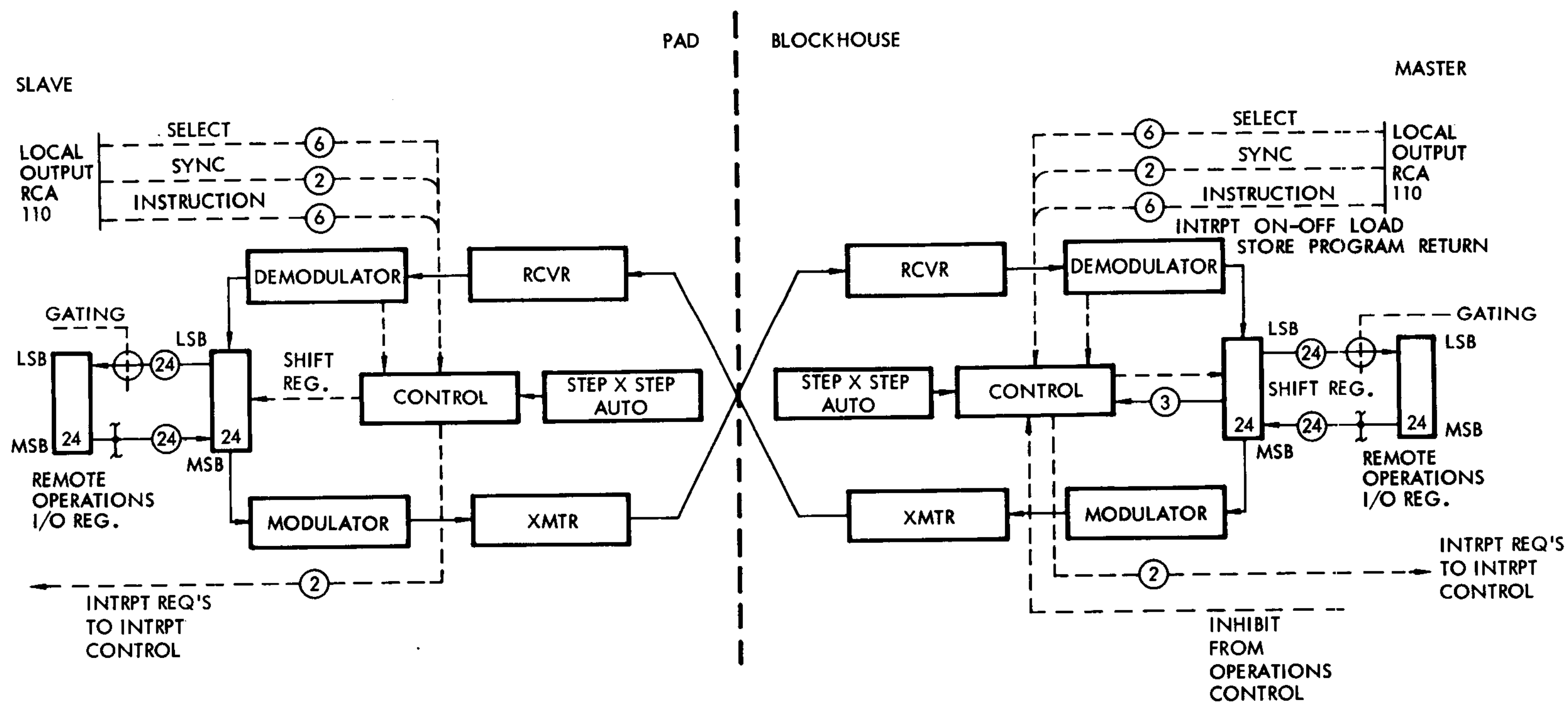

Figure 6-6. Computer-to-Computer Communication Under Interrupt Control

6.3.4.3 Types of Telemetry Systems

Because the C-5 spaceflight missions are more complex, and because this increased complication requires the telemetry system to be more extensive and more accurate, it follows that the handling of data must be automated to a greater degree. Accordingly, the C-5 vehicle will probably carry telemetry systems utilizing computer techniques. In particular, the airborne telemetry systems that furnish data to the computer complex are assumed to be of the pulse code modulation type (PCM).

There will continue to be requirements for frequency-multiplexed systems to provide high-frequency data with lesser accuracy. However, this data would normally not be used in prelaunch checkout or for automatic control of a subsystem during flight.

6.3.4.4 Data Utilization

All of the data from each digital telemetry system will be fed to the computer complex through a single transmission line for each telemetry system. The computer will sample certain channels of this data in a digital form and provide processing and status reporting as necessary.

6.3.4.5 Sampling Speeds

With the use of automatic data handling in the vehicle, telemetry sampling speeds may be increased. This will result in the ability to handle higher frequency data.

6.3.4.6 Equipment

The telemetry ground station equipment will be similar in operation to the C-1 ground station except for the emphasis on digital data. A simplified block diagram is shown in Figure 6-7.

The telemetry control and display console is essentially identical to the C-1 console shown in Figure 5-9. Spectrum analyzers are used on FM/FM systems.

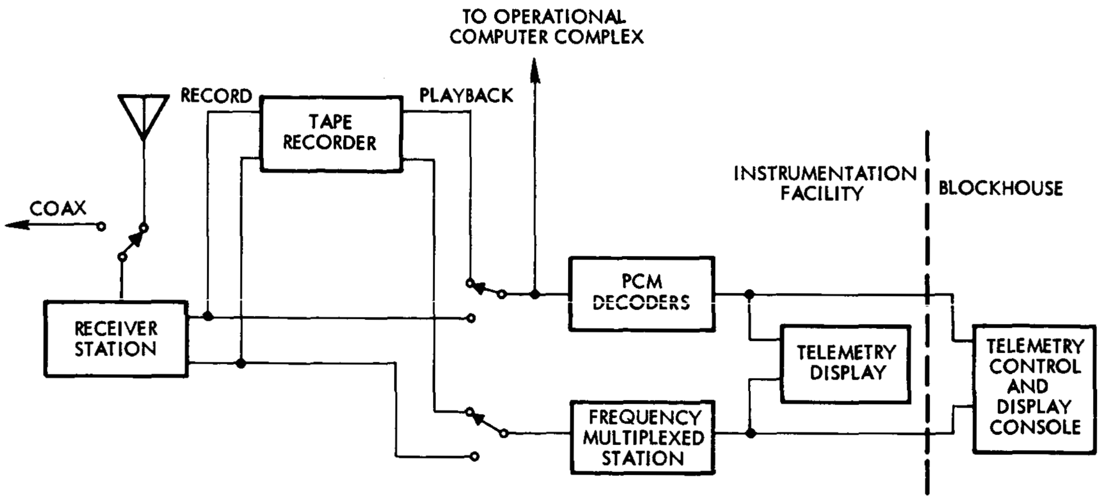

Figure 6-7. Simplified Block Diagram of C-5 Telemetry Ground Station

The chief telemetry operator can quickly select any data channel from any PCM system and display it on an oscilloscope for failure analysis purposes. This choice is unavailable to the console operator since he is not concerned with failure analysis, but only with viewing normal data during the progress of a test.

6.3.4.7 Computer Tie-In

The telemetry-computer interface for the C-5 system is essentially the same as the digital portion of that described in Section 5.3.3.10 for the C-1 complex. Since digital data is emphasized in C-5, however, data rates must be even more carefully considered. The limiting factor is the subroutine required to read in information. With a loop of six instructions requiring 435 microseconds, the maximum acceptance rate is 2300 words per second. If a greater rate is required, an external telemetry buffer must be provided as mentioned in Section 5.3.3.10.

6.3.5 Launch Control Console

Once the data link is closed, the launch control console, shown in Figure 6-8, is the primary control for all operations. It contains the necessary interlocks and logic for control of the operational sequences. For test operations, the computer control console programs all test sequence after

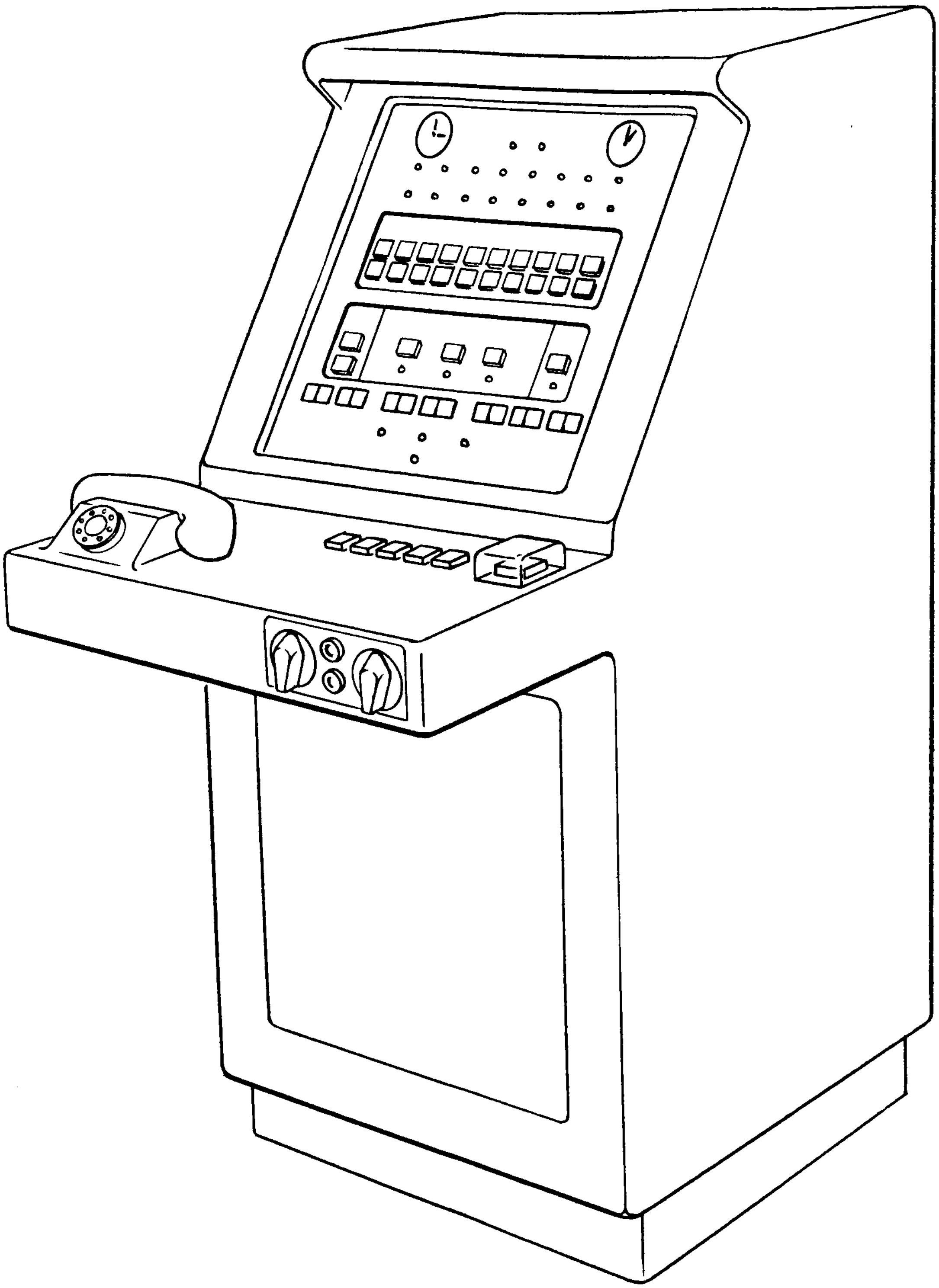

Figure 6-8. Launch Control Console

being enabled by the launch control console. Once test operations have been completed, control of fixed operational sequences conducted by the computer is exercised by the launch control console.

6.3.5.1 Description

Again in C-5 it is assumed that no more than four fixed sequences are needed for launch operations. These sequences, previously discussed in Section 5.3.4.1, are performed in a sequential manner. Thus, a previous sequence must be completed satisfactorily before the next sequence can start. The launch control console sequential control selects the proper computer sequence by the operations sequence select switches. Electrical power to the vehicle is also activated by the launch control console, although switching of the power is under computer control during the sequences.

A minimum amount of information is displayed upon the launch control console, since any malfunction or "no-go" indications read directly upon the computer control console, which is adjacent to the launch control console. As stated previously, this console also contains those permissive interlocks from external sources, such as range safety, operational flight control, etc., which are required to initiate either propellant loading or launch.

Other indications include arm, ignition, liftoff, and automatic cutoff if such should occur. Time indicators show the elapsed time of the sequence in process, the point to which the sequence would be recycled, and the time to launch.

The console can command an abort of the payload from the pad, should the occasion arise. This capability is provided by both hardline and r-f link, and not through the computer data link. A typical layout of the launch control console appears in Figure 6-9.

If desired, additional controls may be added to the launch control console, such as control of water systems and fire protection systems through hardlines to the launch site. When the design of the launch complex has been made definite, studies will be needed to determine the optimum and necessary controls, exclusive of those utilized through the computer.

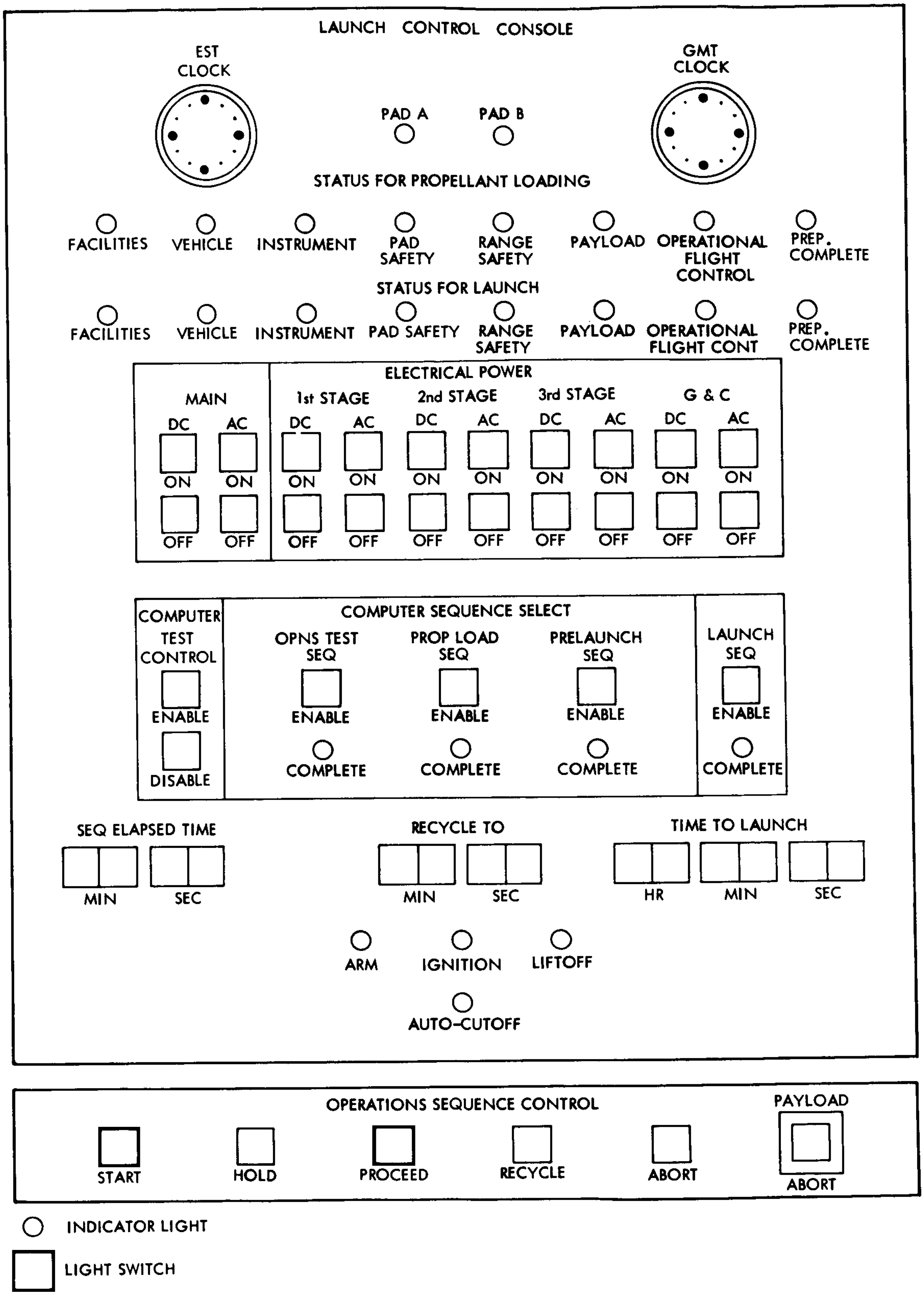

Figure 6-9. Launch Control Console Panel

The computer program contains the necessary instructions to maintain a safe condition in case of a "hold," as well as for recycling in any particular sequence. As part of the final launch operations sequence, appropriate instructions are given for returning the facility to a safe condition after launch or in case of an aborted launch sequence. This includes any action made necessary if automatic cutoff occurs after ignition.

The propellant loading sequence is controlled at the launch control console. All information as to the status of the loading operation is contained on the propellant loading console, which is adjacent to the launch control console. For operational control, the computer control console, the propellant loading console and the launch control console provide complete information and control for all operations necessary for the final checkout and launch of the Saturn vehicle. (See Figure 6-10.)

6.3.5.2 Computer Tie-In

Communication between the computer and the C-5 launch control console is essentially the same as for the C-1 (refer to Section 5.3.4.2) extended to handle the more complex console. Communication with the operational computer is via the discrete input and output lines, and via the operational computer and the data link to the transporter computer. The extensive electromechanical and program interlocks are provided as before.

6.3.6 Propellant Loading Console

The propellant loading console for the C-5 vehicle is identical to the C-1 console described in Section 5.3.5, except as modified by the addition of the S-II stage. This section describes the details of that console shown in Figure 6-11.

6.3.6.1 Description

Figure 6-12 shows the panel layout for the C-5 propellant loading console.

The computer program can be designed to take appropriate action if a dangerous condition arises. Should the computer fail, the propellant loading console need have only the capability of interrupting the computer and defueling the vehicle. In this way, a minimum number of hardlines

Figure 6-10. Computer Control, Launch Control and Propellant Loading Consoles

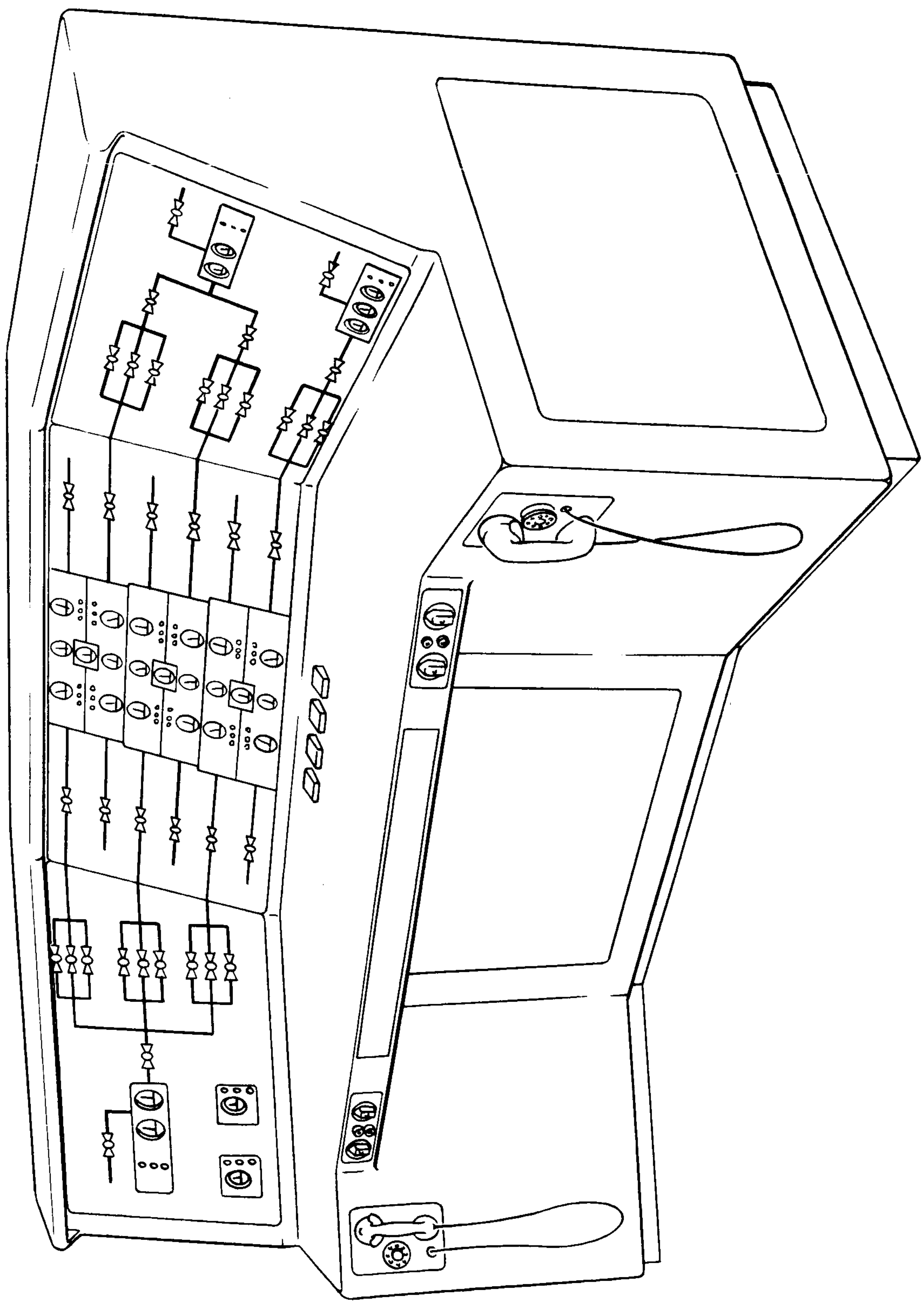

Figure 6-11. Propellant Loading Console

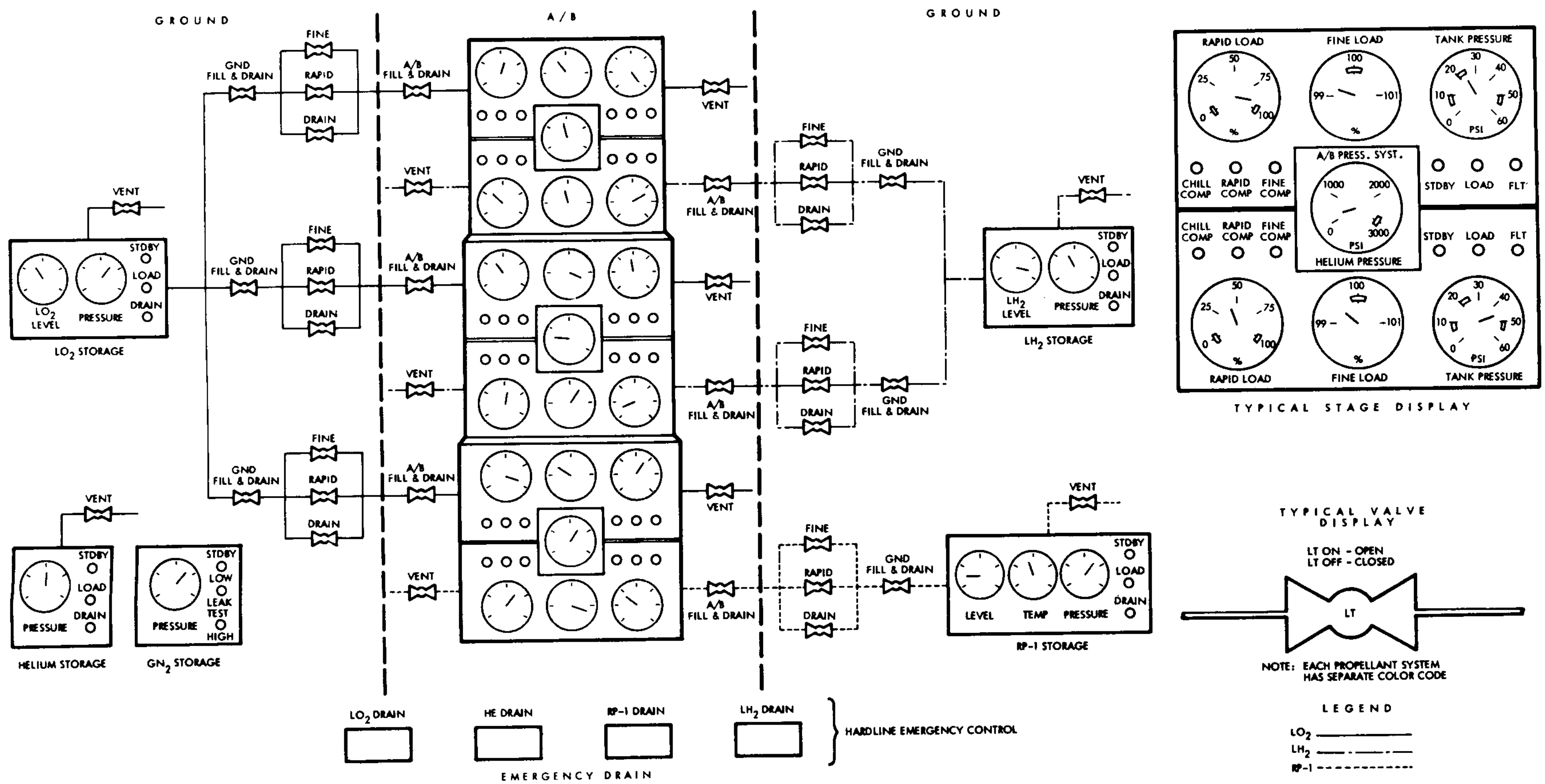

Figure 6-12. Propellant Loading Console Schematic

are necessary for this emergency control, although some logic and sequencing will have to be accomplished at the site when emergency control is initiated. For instance, a single command from the console operator would initiate the closing of loading valves, shutdown of pumps, and opening of drain valves to defuel the missile and interrupt the computer control. With proper computer operation, there appears to be no requirement for manual override capability. The display console utilizes information available via the data link to monitor proper operation of the fueling sequence as well as proper operation of the computer itself.

If a failure in the computer did occur which would change the normal sequence of events, the operations would be terminated until such time as the computer could be repaired. By the same token, a failure of the data link or operational computer would also prohibit continuance of the operations. Thus, the manual override capability of the console is minimum, while allowing a maximum display of information during proper operation.

The display shown in Figure 6-12 is predicated upon a delta pressure loading system. This allows the level of each tank to be ascertained at any time. Upon reaching a predetermined level, the delta pressure indication causes rapid load valves to be shut, maintaining the loading operation under fine load conditions. At this time either a partial delta pressure transducer or point sensor can be utilized for final topping and replacement of propellants lost during boiloff, to give greater accuracy to the loading system.

All necessary interlocks and control of the computer program are in the launch control console, which initiates the loading sequence. The emergency defueling capability of the propellant loading console would interrupt and disconnect the computer's operation as well as taking the necessary action to defuel the missile. The propellant loading program utilized by the computer is designed to sequentially start the loading of all stages, so that propellant loading is accomplished in a minimum of time and completion of all stages occurs simultaneously.

The display panel will utilize the information from the computer so that the status of propellant loading can be determined at any time during the sequence. Should an error or an unusual propellant loading situation be detected by the computer, the computer would be programmed to go into an interrupt or "hold" status, whereupon the computer control console operator could ascertain what the "no-go" condition is so that appropriate action could be taken.

In addition to displaying propellant loading status, this console also displays information concerning the pressurization system of the vehicle and facility. The basic assumption has been made that the airborne pressurization storage tanks will be located within one of the cryogenic propellant tanks so that additional chilldown will not be necessary. Should such not be the case, the liquid nitrogen chilldown system and helium temperatures could be added to the displays. A further assumption is made that gaseous nitrogen will be utilized for the pressurization system until such time as propellants are to be loaded on board. The helium pressurization system, both facility and missile, will be controlled and loaded aboard the vehicle under computer control.

Only those controls necessary to return the missile to a safe condition are located on this console. These controls are used only if a computer malfunction places the vehicle in a hazardous condition. Therefore, while the displays are fairly comprehensive in showing the status, the controls are only of an emergency nature. Loading of the pressurization system is programmed as part of the propellant loading sequence. The computer program is designed to recognize emergency conditions and take the necessary action.

Accurate loading is maintained by calibration of the delta pressure transducers by the method outlined in Section 8.5. The computer could utilize this calibration to change factors for final propellant levels. A typical loading sequence would be similar to that previously described in Section 5.3.5.1 with the addition of those functions required by the S-II stage, which in turn would be similar to the S-IV stage.

6.3.6.2 Computer Tie-In

The operation of the propellant loading console for C-5 is identical to that described in Section 5.3.5.2, except for the expansion of the display to cover an additional stage.

7. COMPUTER OPERATION CONSIDERATION

This section discusses the general operations concept recommended for effective use of the automation system. Included are such items as test sequence programming, loading and verification, and self verification of the automation system. Also contained in this section is a description of the guidance system and its interface with the automatic checkout equipment.

7.1 Test Programming

Two approaches may be considered in writing the programs for the Saturn automation system: writing directly for and debugging on the RCA 110 computer, or using an intermediate computer such as the IBM 7090. The final choice is dependent on the projected availability of the 110. Since this is not known by STL, and since it is probable (at least during some phases of the program) that 110 time will be at a premium, the latter approach is considered here.

To implement this approach, two 7090 programs are required. The first is a compiler, which will accept as input a symbolic deck of the SAP or SOS type and will have as its output a program for the RCA 110. The second routine is a 110-7090 interpretive routine for running 110 programs on the 7090. With these two programs, it is possible to write a program for the 110 wherever a 7090 is available and to check the program out completely.

The basic requirement in the preparation of test sequence routines is to allow the programs to be written by an expert in the system under test, rather than a programmer. Using the compiler routine mentioned above to translate from "test language" into 110 language, the following procedure will be followed:

a) The test sequence is specified in a simple English language form (as in Figure 7-1), which can be understood and learned almost immediately. For each step in the sequence, the following information is written on the form:

Test Sequence No. ______________ Written By ______________ Approved By ______________

Date ______________ New ______________ Replacement ______________

Test Point	Component	Stimulus Point	Type of Stimulus	Measure Point	Type of Measurement	Upper Limit	Lower Limit

End of Test Sequence ______________

Figure 7-1. Sample Test Sequence Initiation Form

1) The component being tested

2) The point at which the stimulus to test the component is given

3) The nature of the stimulus

4) The point at which the result of the stimulus is measured

5) The nature of the measurement to be made

6) The permissible upper limit of the measurement

7) The permissible lower limit of this measurement.

In addition, the following is required for the overall test sequence:

1) The name of the person writing the test sequence

2) The date of the writing

3) The test sequence number

4) A tag telling if this sequence is a new one or if it is to replace a test sequence already written.

b) This form is then given to a key punch operator, who punches the information on IBM cards and gives the cards to the 7090 operator.

c) The 7090 operator uses these cards as the input to the 7090 compiler routine, which proceeds to:

1) Translate the input cards.

2) Write a test sequence subroutine for the RCA 110.

3) Write two new identical test sequence tapes using as inputs the old test sequence tape and the group of test sequences just compiled from cards. These tapes are in a form which can be read by the RCA 110 and which consist of relocatable RCA 110 instruction. Two new test sequence tapes are needed so that one can be used with the 110 while the other is available for making further test sequence changes on the 7090.

4) A listing of the test sequences on tape is made, and a detailed printout of the new test sequences (in an easy-to-understand manner) is made for checking by the author and for reference.

Figure 7-2 illustrates this procedure. The advantages are:

a) The person writing the test sequence does not need any kind of programming knowledge. He need only know how to fill out the form.

b) There is a minimal amount of handling of paper, cards, and tape.

c) The RCA 110 need not be interrupted when a new test sequence tape is written.

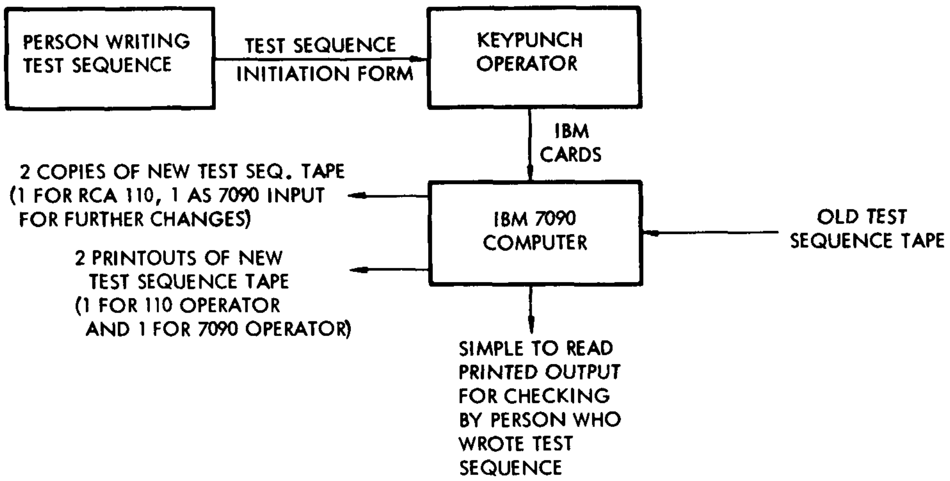

Figure 7-2. Block Diagram of Programming Procedure

7.2 Test Program Loading and Verification

7.2.1 Loading

The program is initially loaded from the magnetic tape. A loading supervisory routine stores the programs on the appropriate place on the drum. The programs on drum are then:

a) A loading supervisory routine

b) Input-output routines

c) An execution supervisory routine, which is the routine that "talks" to the test sequence control console.

The computer start-up procedure is fairly simple. After the power is turned on, it may be necessary to load all those programs mentioned in the paragraph above. Usually all that will be necessary is to manually transfer control to a short input routine in core memory, using the computer console. This causes the execution supervisory routine to be read from the drum into core.

On a given day it may not be necessary to use all the test sequences and diagnostics from the magnetic tape. Once the operator has decided which test sequences will be needed for the day, he enters the test sequence numbers, using the typewriter input to the RCA 110. The sequences are picked up by a subroutine which takes all the test sequences called for and puts them on the drum. A table is formed which tells which test sequences are on the drum and where the starting location of each test sequence is.

The operator must still retain the ability to perform a test sequence which he did not call from tape when he chose the test, and add or delete test sequences in the drum storage as he wishes. The sole restriction is that the test sequences do not take up more storage space than available on the drum. If this is the case, the operator gets a message on the typewriter advising him of the situation. He is also advised as to the amount of drum storage still available for other test sequences. Each time a deletion or addition is made, the operator receives a listing of all the test sequences on drum.

The advantage of this type of loading procedure is that it makes available to the operator a large and varied number of test sequences on tape, without slowing up the 110 by requiring extensive tape reads. The ability to add and delete test sequences from the drum also adds greatly to the overall efficiency of the system.

7.2.2 Program Verification

Verification of the operating condition of the computer is, of course, of primary importance in a system of this type, and is discussed in Section 7.3. No test can be considered complete, however, unless there are means of verifying that the program is correct in the memory. This is especially important after the program is loaded. There are many ways of doing this; their efficiency and effectiveness depend largely on the details of the computer logical implementation. One method, for example, is to use a "check sum" for each routine. This technique sums up each word of the routine, both instructions and data (ignoring overflows), and compares the result with a previously determined value. A problem can arise if there are manually inserted constants in the program, particularly if this method is used for other than program verification upon initial loading.

Another method is to check the computer memory periodically against "hardened" tape. Whenever the computer memory differs from the tape, this fact is visually displayed to the operator as well as printed out. This printout is compared to a program listing and the memory corrected. The correction process will use the typewriter input for a small number of changes or tape input for a large number.

7.3 Self-Verification of the Automation System

The self-verification techniques for the system fall into two areas: the self tests internal to the computer, and the overall system tests. Since the overall system tests have the greatest effect on the hardware, the tests must be carefully planned. Aside from such standard techniques as testing all indicator lamps, a minimum requirement is to generate in the computer analog output channels a stimulus which is then measured by the analog input channels. This approach can be extended to different types of stimuli using a variety of channels. Further elaboration could involve the use of special-purpose hardware to exercise the system. The details of verification equipment and techniques must, of course, be determined by the exact system implementation. However, it is of vital importance to emphasize this area in the initial system conception to ensure the success of the automatic checkout system.

Computer self-verification techniques are generally well known, and merely require application to a specific system. However, the detailed programming effort involved can represent a sizable effort in terms of manpower and time.

Two major verification routines should be used. The first, which is quite extensive, checks the computer and peripheral equipment. This routine requires several minutes of running time, and is used during system turn-on and prior to critical points in the checkout and countdown.

The second routine is a less extensive version of the first. It is stored with the test sequence programs, and can be used at any time by the test operator to verify the operation of the computer.

A very short test program should also be provided for use when no test sequence is active. Then, whenever the "proceed" button is pressed, the test routine is interrupted and control is sent to the execution supervisory routine for performing test sequences. After the test sequence has been performed, the test routine is automatically put back in operation.

7.4 Guidance System

This section describes the Saturn guidance system and its relation to the automatic checkout equipment. Several assumptions have been made (as indicated below) as a basis for discussing this important part of the overall space vehicle and its interface with the launch control equipment.

7.4.1 Guidance System Characteristics

The basic guidance system for the Saturn C-1 vehicle, beginning with SA-5, is an all-inertial, digitally programmed unit using an adaptive guidance mode for maximum injection capability. This system also computes or provides the flight sequencing functions, such as staging, engine cutoff, etc. Major subsystems of the guidance system consist of an MSFC inertial measurement unit and a digital computer. Auxiliary equipment includes various electronic amplifiers, analog-to-digital converters, digital-to-analog converters, signal conditioners, multiplexers, and power supplies.

For the Saturn guidance and control system, there are two modes of operation and these are interrelated functionally and in the manner in which they are mechanized. The control mode takes account of the basic stability requirements of the vehicle and provides proper control torques to overcome any disturbance of the vehicle's attitude from a desired reference. The guidance mode determines the trajectory which the space vehicle will follow in attaining the correct velocity vector, space coordinates, and time of arrival of the space vehicle with respect to its destination. Many practical and desirable considerations also were taken into account for the guidance mode so as to optimize certain chosen parameters. For example, by minimizing the amount of propellant required for a given mission, the size of the spacecraft may be increased.

The guidance system utilizes the ground computer complex to communicate with the space vehicle's computer and platform for checkout and countdown purposes. This allows a continuous change of the flight program constants and platform aiming azimuth. This hardware capability, combined with the allowable launch window variations afforded by the adaptive guidance mode, should meet any foreseeable injection requirements.

7.4.1.1 Computer Characteristics

The computer is a serial, binary, complete-value, all-drum unit. It can store over 6000 instructions, and approximately 1000 fixed independent constants.

The input-output circuits handle 1000-cps real-time signals, three attitude inputs, 41 discrete inputs, three incremental velocity inputs, 12 discrete outputs, three d-c analog outputs, and five-bit ground communications.

During the various preflight and launch countdown modes, the computer can perform the following functions:

a) Memory drum run-up sequence and self-check, including proper operation and computation

b) Load and verification of constants

c) Simulated flight computations

d) Scale factor adjustment for outputs of the inertial measurement unit

e) Accelerometer calibration by first torquing the platform gyros to obtain 1-g positions and then correcting scale factor and bias terms

f) Gyro drift measured and compensation.

The flight program instructions are inserted in the computer before the guidance system is installed in the vehicle. The 30 instruction tracks are loaded by removing the memory drum from the computer and inserting the 6000 instructions using memory drum loading equipment.

7.4.1.2 Inertial Measurement Unit Characteristics

All inputs to the guidance control modes are obtained primarily from the stabilized platform of the all-inertial system. The outputs of the platform are space-fixed inertial data from three mutually perpendicular accelerometers required for the guidance mode, and highly accurate reference attitude information in pitch, yaw, and roll for stabilization of the vehicle in the control mode. Control accelerometer outputs are combined with the accurate attitude information to limit any excessive buildup of the vehicle's angle of attack during critical periods of flight. Rate gyros and differentiating networks provide attitude rate signals.

7.4.1.3 Guidance System Interface with Ground Support Equipment

It is assumed that multiple interface links between the two units of the guidance system, the missile control system, the ground support equipment, and the telemetry system will be similar to that shown in Figure 7-3 and Table 7-1. Many of the signal inputs and outputs require amplification, attenuation, signal conversion, or multiplexing of the base signals.

Signals from the various components include:

Digital signals (A, D, F, L, S)	27-bit lengths (24 bits for data and 3 bits for telemetry synchronization)
Pulse trains (H, R, U)	Signal magnitudes are represented by the number of pulses for a given period of time.

Discrete signals (C, E, I, K, N, P)	±28 vdc, ±15 vdc
Analog signals (V, G, J, M, Q, T)	0-30 vdc 0-115 vac at 400 cps 0-30 vac at 1000 cps

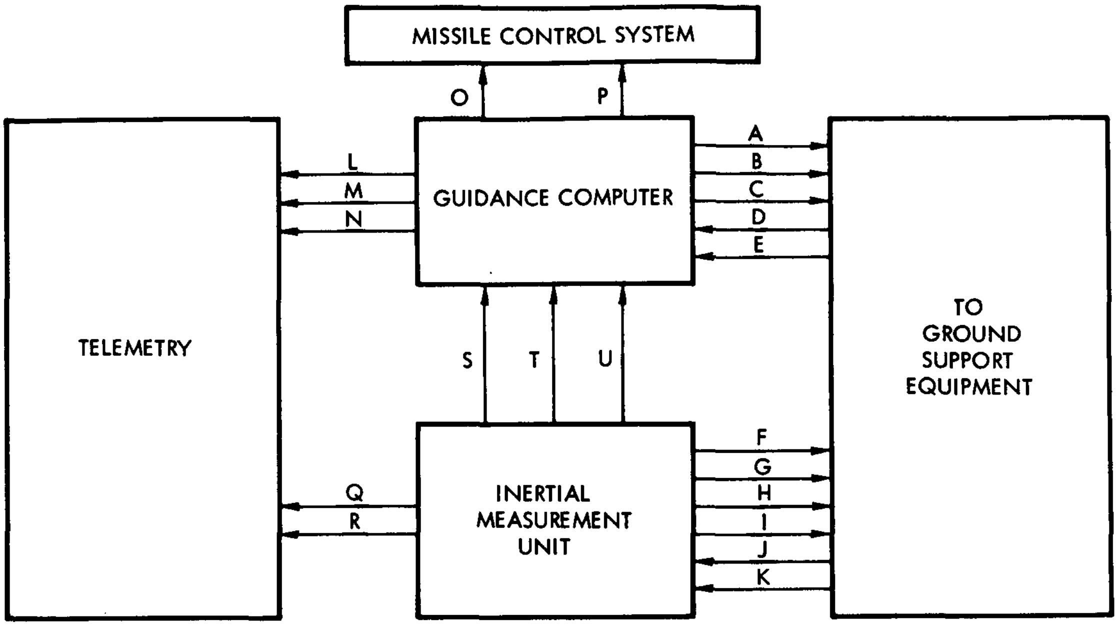

Figure 7-3. Block Diagram of Guidance System Interface

7.4.3 Test Operations

Many of the guidance system test and calibration operations are performed as part of special test routines stored within the guidance computer. Initiation and monitoring of these test routines are performed by the ground computer complex. In addition, the guidance system has a number of standard modes of operation, such as heat, standby, align, ready, and inertial, all of which will be initiated and monitored by the ground computer.

The expected signal interface between units of the guidance system and the ground computer has been described in the previous subsection. Although a definition of a typical test operation is not attempted here, the following signal flow may be taken as representative of what is required to test and launch the vehicle.

Table 7-1. Interface Links

Signal Line	Approximate Quantity	Data Type	Typical Signal
A	20	Serial Digital	Velocity
B	13	Analog	Steering Command
C	30	Discrete	Flight Command
D	25	Serial	Constant Loading
E	40	Discrete	Mode Indication
F	8	Serial Digital	Identification
G	20	Analog	Amp Output
H	20	Pulse Train	Gimbal Angle
I	20	Discrete	Gimbal Limit
J	20	Analog	Gyro Torquing, Power
K	10	Discrete	Mode Command
L	20	Digital	Velocity
M	5	Analog	Steering Command
N	12	Discrete	Flight Command
O	3	Analog	Steering Command
P	12	Discrete	Flight Command
Q	30	Analog	Amp Output
R	27	Pulse Train	Acceleration
S	8	Digital	Identification
T	10	Analog	Power
U	10	Pulse Train	Acceleration

a) GSE to guidance system (D, E, J, K)

   1) A-C, two-phase power (until power transfer)

   2) 28-vdc power (until power-transfer)

   3) Test sequencing signals to both inertial measurement unit and guidance computer

   4) Approximately 50 command discrete inputs, such as tape read, attitude error feedback, system status, etc.

b) Guidance system to GSE (A, B, C, F, G, H, I)

   1) Approximately 60 discrete signals indicating conditions, modes, or various "no-go" indications, such as gimbal limit switch activation, system "go," system "no-go," system in checkout, system ready, system in memory, system in inertial

   2) Steering command signals, either in analog or digital form

   3) Guidance commanded ground computer operations

   4) Verification signals of computer response to ground computer commands.

Except for application of ground power, all of these signals with minor conditioning are compatible with input-output equipment of the ground computer complex.

7.4.4 Flight Data Insertion

Data loading of the computer consists of several hundred constants plus various identification indicators. These constants include matrix values for transforming velocity signals to theoretical coordinates and scale factor, drift, and compliance terms for use in correcting velocity bias terms, gyro torquing rates, and accelerometer nonlinearity. Flight program data is also inserted. This data includes:

Pitch and yaw steering computation constants

Velocity-to-be-gained computation constants

Gyro and accelerometer offset constants

Stage cutoff computation constants

The data insertion is normally accomplished by special equipment which provides a punched tape read-in and verification by read-out on punch tape. However, to accommodate a variable launch window, it is necessary to vary a few of the flight constants up to the instant of launch. For those few data words requiring such change, the ground computer will be utilized to make the necessary computation and to send the proper digital words to the guidance computer for storage.

8. AUTOMATION OF MECHANICAL TEST OPERATIONS

This section contains a discussion of automation techniques for mechanical test and launch operations. The work was performed in response to an indication by MSFC that mechanical test areas should be given special emphasis during the study. The approach taken was to examine the overall testing requirements and then to identify particular areas for detailed study, such as transducer calibration, leak detection, propellant loading, etc. These areas were then investigated to determine possible methods and relative feasibility of automating the required operations.

8.1 Overall Testing

The mechanical test operations considered here occur after vehicle assembly. These operations include assembly area tests, ordnance and high-pressure leak test during movement to the launch pad, launch area tests, propellant loading, and launch operations checks. In the event of an aborted launch, a recycle sequence requires additional checks during unloading of propellants and possibly an engine purge sequence. Most of these tests and operations are capable of being fully automated. These include engine sequencing tests, pressure switch checks, pressure transducer calibrations, propellant loading operations, proper mating of connectors, etc. Other tests may require manual action because automation is unduly complex. These include leak checks, ordnance checks, and pump speed transducer calibrations.

8.1.1 Post-Assembly Tests

The mechanical tests that can be automated after vehicle assembly include the following:

a) Engine sequencing and timing

b) Igniter system electrical characteristics

c) Thrust vector control actuation system static and dynamic response

d) Propellant loading system sensor calibration and checkout

e) Operability of auxiliary equipment, such as valve heaters

f) Continuity and proper mating of stage and interstage connections.

Techniques for automating these tests are discussed in subsequent sections.

8.1.2 Ordnance System Tests

Ordnance items are checked out during installation at the ordnance area. After installation, automated electrical tests can demonstrate that the installation is safe for other vehicle testing. Studies need to be conducted to determine if additional checks are required and to what extent they can be automated. As an example, igniter squib continuity checks would require arming for automated checkout. This procedure may be prohibited by range safety because of the hazard.

8.1.3 Launch Area Tests

The launch area test sequence will repeat most assembly area tests. Additional tests are required after mating with such launch facility systems as the pneumatics and propellant loading systems. Use of the same checkout equipment for both assembly and launch area testing eliminates the test equipment as a variable, thereby simplifying the detection of degradation in the flight equipment. Other considerations that affect the selection of launch area checkout equipment and procedures include the required test content, the characteristics of the system under test, and the urgency of the launch preparation.

8.1.4 Propellant Loading

Propellant loading should be completely automated in the interests of speed. The problems of attaining loading accuracy in large hydrogen-fueled vehicles are major and require considerable study. Some techniques that appear to be feasible and compatible with automation have been discussed previously in connection with operation of propellant loading consoles for the C-1 and C-5 automation consoles. Additional detail is introduced in Section 8. 5.

8.1.5 Recycle Sequence

The amount of work required for system recycle after an abort depends upon the time of abort and is usually more extensive than the initial vehicle checkout. For example, it may be necessary to purge and clean thrust chambers after an abort, whereas this operation is normally performed prior to vehicle assembly and whenever contamination is suspected. The high degree of flexibility required of the recycle sequence, combined with the crucial nature of initial recycle operations (such as defueling), makes the use of a computer desirable.

8.1.6 Reliability

Launch reliability is determined by the reliability of the complete system, consisting of vehicle, test and support equipment, and facility. The conflicting requirements of vehicle component reliability versus final checkout schedule warrants special consideration. If all components are checked immediately prior to launch, maximum confidence will exist in vehicle operability. However, the test system required for such checks may be too complex to be practical. Trade-off studies should be included as part of an inquiry into optimum checkout sequence and methods.

8.1.7 Instrumentation Calibration

It is desirable to make maximum use of the flight instrumentation system in preflight testing. Instrumentation calibration should therefore be done early in the checkout sequence. Automation of instrumentation calibration by automatically programmed pressures and electrical stimuli is feasible in most instances. Certain instruments, such as pump speed indicators, require special study to select practical calibration methods.

8.1.8 Maintenance and Checkout Considerations Affecting Design

If launch schedules are to be maintained, not only must checkout, propellant loading, etc., be accomplished expeditiously, but repairs (at least minor ones) must be made in minimum time. Hence, repair procedures must be considered in planning prelaunch operations, and in the design of the vehicle, checkout equipment, and facilities.

When a component failure occurs during a prelaunch test, a decision must be made as to which of several possible corrective actions shall be taken. For example, a decision may be required on whether to remove and replace a component, a major subsystem, an engine, a cluster of engines, a stage, or the entire vehicle. Delay incurred in repair versus delay incurred in replacing the component or a larger element than the failed component must be evaluated. The stocking of spares must be compatible with the planned level of maintenance. Mission considerations may or may not permit replacing the vehicle. The extent to which major components and engines shall be removable and replaceable on the vehicle at the launch pad must be determined early in the program because the maintenance philosophy affects the basic vehicle design. Factors which affect the remove-and-replace capability include structural considerations, requirement for acceptance test firing or other special calibration, and matching of engine subsystems or engines within a cluster.

A study of servicing and checkout methods should be made early in the program so that vehicle, facility, and support equipment designs may incorporate provisions for easy servicing and checkout. Areas of study should include:

a) Total quantity of nitrogen, helium, and other test fluids required for servicing and checkout, including consideration of requirements for performing functions simultaneously

b) Determination of quantity, kinds, and locations of intercluster and interstage connections, facility/GSE, facility/vehicle, and GSE/vehicle connections to permit all required simultaneous checkout and servicing functions

c) Detailed designs required to prevent inadvertent misconnections

d) Requirements for purging during countdown, and for flushing and purging during a hold or after an abort

e) Avoidance, where feasible, of requirements for special post-abort servicing or decontamination

f) Checkout and control tie-ins between the individual engines and between stages to permit adequate control and malfunction isolation

g) The use of the same checkout and servicing equipment and procedures from factory checkout through launch.

8.1.9 Automatic Shutdown Simulation

It is assumed that propulsion system cutoff sequencing controls for cluster engine shutdown will be part of the auxiliary ground support equipment. Engine pressure sensors monitored on a start sequence time basis generally provide the necessary information.

The computer could provide both normal and abnormal engine start sequences. The computer would in turn monitor responses to test for proper capability of sensing, for proper sequence, or for required automatic cutoff. Proper response of the launch sequence, launch control equipment, and vehicle would be tested under emergency abnormal conditions while the vehicle is in a safe condition.

8.2 Pressure, Temperature, and Flow Sensors

Pressure, temperature, and flow sensors will be utilized for many test operations, flight instrumentation, vehicle and facility status information, abort system, and other applications. Automation of sensor checkout and calibration will increase confidence and reliability, since these checks may be made just prior to the launch sequence.

8.2.1 Pressure Sensors

A technique for automating the checkout and calibration of all pressure sensors, both facility and vehicle, is described in this section. It consists of providing a solenoid-operated shuttle manifold which could be common for the vehicle or each stage, as shown in Figure 8-1. The pressure source in the manifold is under computer control and used for calibration of the many pressure sensors. A typical pressure profile, as programmed to the manifold, is shown in Figure 8-2. The supply source and manifold are sized to negate the effect of the pressure logs in the system.

The solenoid-operated valves are controlled by the computer, using facility power supplied through an umbilical connector. During the pressure program, the valves are so activated that the sensors may see only their normal range of pressure. This prevents any overranging or damage to the sensors. Pressure switches are checked for activation and deactivation at the proper pressure input level. Pressure transducers are calibrated against the programmed standard. This technique not only checks out operational sensors, but also allows more accurate propellant loading if delta pressure sensors are used and calibrated, as discussed further in Section 8.5.

The solenoid-operated valves are fail safe in the direction of normal sensor operation. Since facility power is used for activation, inadvertent valve operation after launch is precluded. One or more check valves in the pressure supply manifold protect against leakage.

8.2.2 Temperature Sensors

Automated checkout of temperature sensors requires further investigation. Initial studies indicate that it may be more feasible to use redundant sensing elements than to attempt automatic calibration.

8.2.3 Propellant Flow Sensors

Propellant flow sensors can be calibrated by introducing propellant flow across the sensing element after vehicle fueling. The desirability of automating this operation depends on the use to be made of the flow sensor and the complexity of the additional test equipment. Additional studies are required in this area after more specific knowledge is available about vehicle design, flow sensor usage, and calibration requirements.

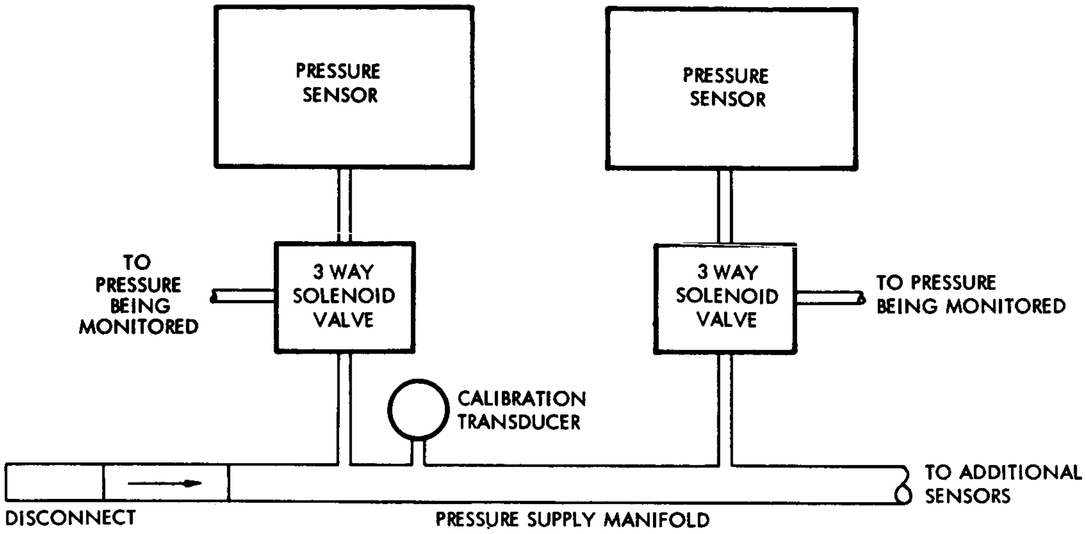

Figure 8-1. Typical Pressure Sensor Calibration Arrangement

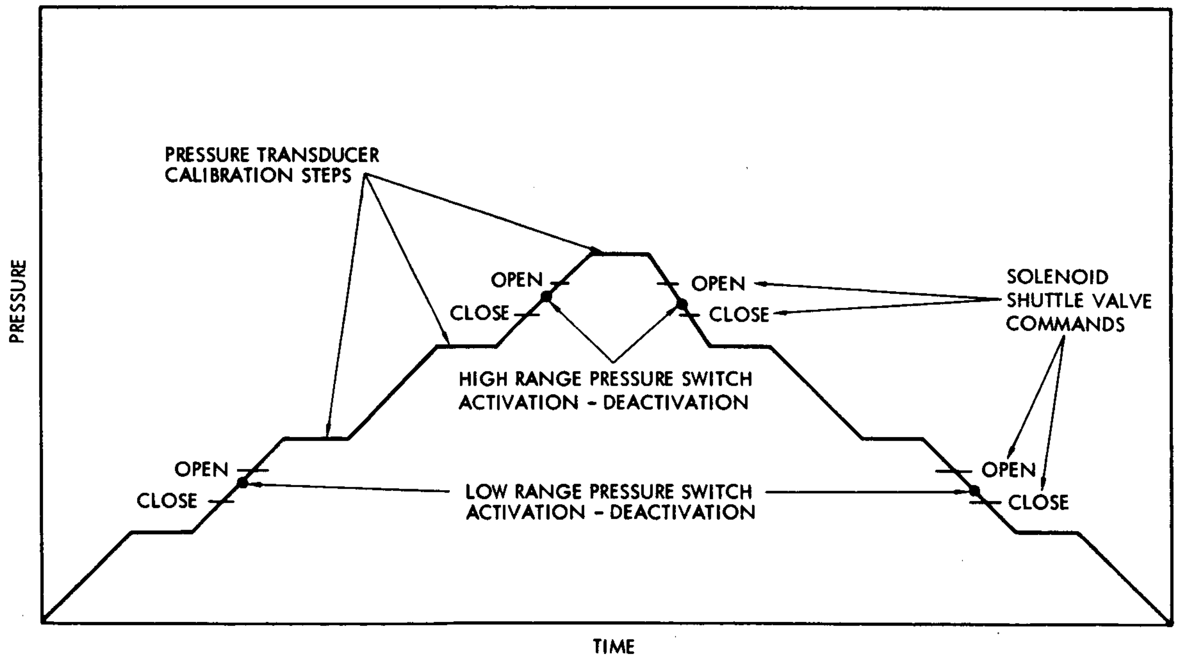

Figure 8-2. Pressure Profile for Pressure Sensor Checkout and Calibration

8.3 Leak Detection and Measurement

Leak detection and measurement techniques are intimately associated with detail vehicle design. For this reason, it is difficult to foresee exactly how leakage testing can best be accomplished and automated for the Saturn. However, certain techniques used on existing vehicles are adaptable in varying degrees to the Saturn. The uses and limitations of existing techniques are discussed in the following paragraphs.

The entire airborne plumbing system is generally checked for pneumatic leaks, with the system divided into subsystems to facilitate the test operation. Each subsystem is selected such that a maximum allowable gross leakage value may be assigned. However, within each subsystem, certain individual joints and seals also may have stipulated values of maximum allowable leakage that must be checked. In general, most attention is focused on specific joints in the early phases of assembly with emphasis shifted to total leakage as progress is made toward the launch, except for a few plumbing areas of critical nature.

In order to establish test requirements, each area of the plumbing system is analyzed to determine the locations and extent of likely leakage, the effects of a leak at each location, the times when these points must be checked for leakage, the best leak test method and equipment for performing the check at each required time, the maximum acceptable leakage values for each subsystem, and the maximum acceptable leakage at each point. Generally, minor leakage on pneumatic systems is less serious than leakage of liquid systems. Also, minor leakage of Lox may be regarded as less serious than equal leakage of fuel or hydraulic oil. Hot gas leaks are usually serious because of their progressive nature and incendiary characteristics. In determining "no-go" leakage values, the above considerations as well as the specific location of the leaks must be included.

In general, as the assembly and checkout process progresses from initial assembly to launch operations, the detection and measuring methods may progress from the simpler manual method to those involving greater automation in detecting and measuring, interpreting the measurements, and making decisions. Also, as the assembly and checkout process progresses, leakage tests tend to become more gross, covering larger amounts of plumbing. When gross leakage is excessive, detailed checks must be made to isolate the causes. The following leakage test methods are commonly employed:

a) Detecting general location of leaks

   1) Pressurize a given plumbing circuit and measure the time rate of pressure decay.

   2) Measure the gas flow required to maintain the given test pressure in a plumbing circuit.

b) Detecting specific locations of leaks

   1) Soap solution

   2) Audible noise

   3) Tracer gas sniffers

   4) Use of seal bleed ducts, manifolds, and envelopes to contain and measure leakage.

Some of the above-listed techniques are suitable for automation, whereas others (e.g., soap solutions) are not. Studies to date indicate that a double seal at the flange joints with a bleed between the seals and a flow measuring device in the bleed line could be used for automated leak checking of a single joint, as shown in Figure 8-3. Details of the flange and seal design, as well as characteristics of the measurement device, depend heavily on system application.

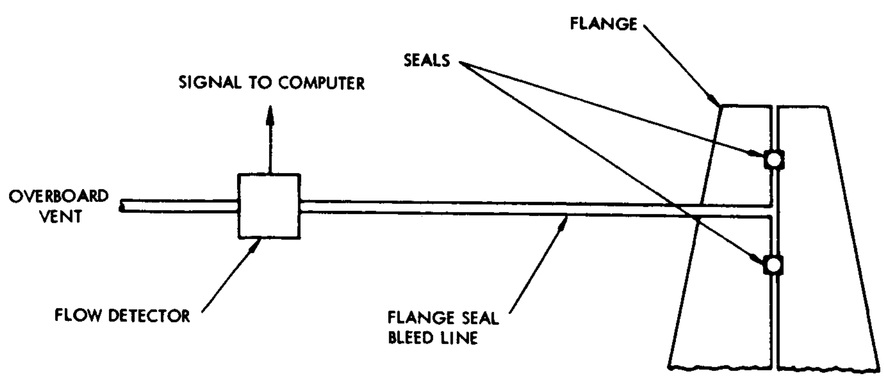

Figure 8-3. Flange Seal Leak Detector

Examples of automated techniques for detection of total leakage of a subsystem or its associated plumbing are:

a) Measurement of time rate of pressure decay

b) Measurement of the flow required to maintain a fixed pressure.

The time rate of pressure decay method uses a pressure transducer or high- and low-level pressure switches connected to the plumbing system being leak checked. Means are provided to pressurize and to cut off the pressure source from the piping without venting. This is usually done with a solenoid-operated valve. The signal output from the pressure sensor may be carried through the umbilicals to the ground system or via telemetry. An alternative technique utilizes pressure transducers or switches installed in the ground with pneumatic connections through quick disconnects to the pressurizing points on the plumbing system.

The leakage flow rate method incorporates a flowmeter in the pressurizing line to the subsystem under test. The flowmeter is usually located in the vehicle and the output monitored through an electrical umbilical, although telemetering may be used. Alternatively, the flowmeter may be located in the ground system and fed pneumatically through quick disconnects to pressurizing points in the airborne plumbing. Either way, the flow rate measured is that required to maintain a constant pressure in the plumbing under leak test.

In general, advisability of automating leak testing should be separately evaluated for each specific application, particularly with respect to the following considerations:

a) Necessity for making a final leak check during or near countdown in view of checks made earlier in the test cycle

b) Complexity introduced by extra equipment required to automate the test

c) Relative reliability of the automated test instrumentation compared with that of system being tested

d) Development lead time required for the automated system and resulting effect on flight schedules.

8.4 Engine Valve Operation and Sequencing

The H-1 engine operating sequence is simple and insensitive to minor variations. Engine components are well developed, and reflect a heavy background of ballistic missile experience. No solenoid valves or electromechanical devices are used in sequencing. Based on these considerations, it appears that valve operation checkout for the H-1 engines could be eliminated after vehicle assembly. However, electrical checks of squib valves and heating elements should be made at appropriate times, and these are easily automated.

The F-1 engine operating sequence is similar to the one used for the H-1, and the same overall checkout philosophy applies. The F-1 engine does, however, employ an in-line ignition detector valve actuated by thrust chamber combustion pressure. Because of the critical function and the need for high reliability, this particular valve should be checked out after vehicle assembly. The technique in Figure 8-4 could be used for automatic checkout with both pressure supplies programmed to appropriate values. The output of the pressure transducer connected to the fuel valve actuator line supplies a proportional signal to the computer for evaluation. This same general technique could be modified in a number of ways. For example, squib-actuated valves could be substituted for the three-way solenoid valve.

The operating sequences of other engines which may be used in upper Saturn stages are more complex than that of the H-1 and F-1 units, and the component design does not have the benefit of as much past experience. Accordingly, it appears that valve operational checks of such engines during or immediately preceding countdown may be warranted at least for the initial vehicles. The main fuel valve of some of these engines incorporates a burst diaphragm which may require replacement after operational checks. The reliability of diaphragm replacement versus eliminating valve checks should be studied.

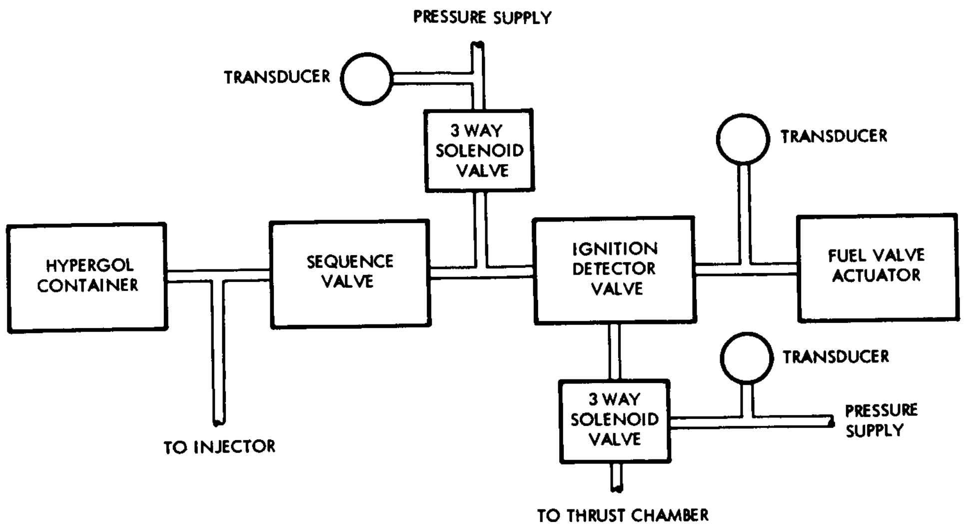

Figure 8-4. Proposed Ignition Detector Valve Checkout System

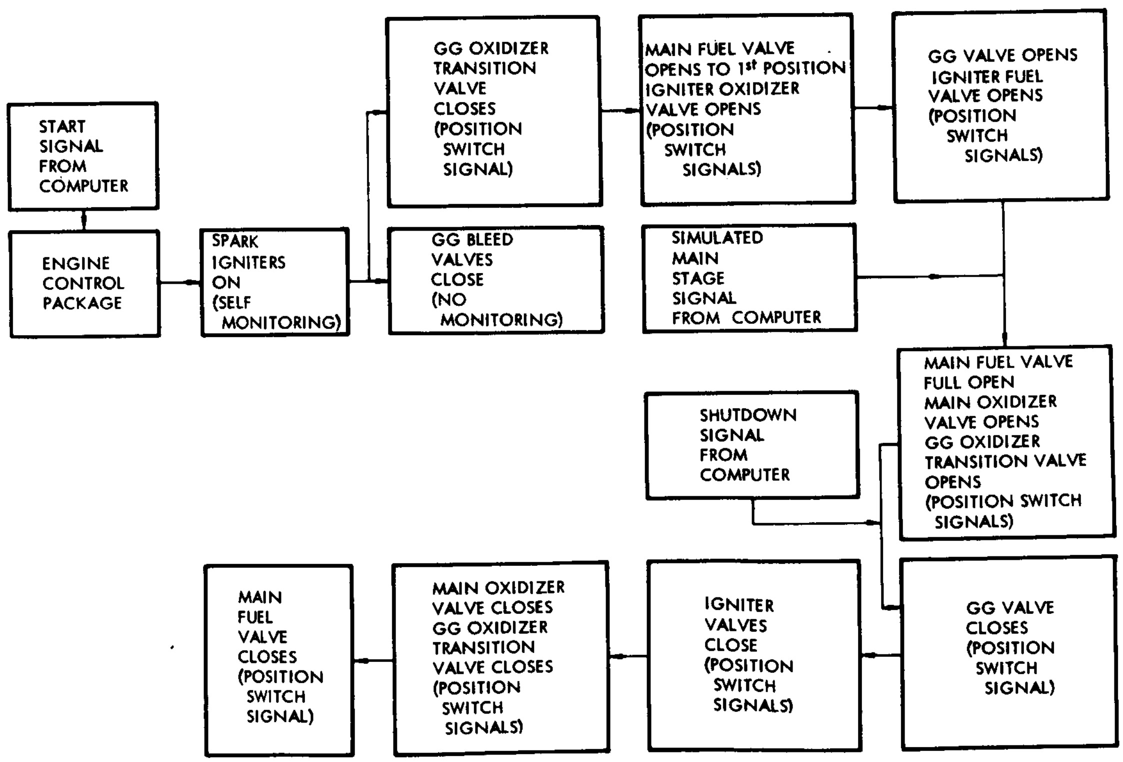

Figure 8-5. Proposed Engine Operational Sequence Checkout

A conceptual operational sequence checkout procedure is shown in Figure 8-5. The computer supplies a start signal and simulated main-stage and shutdown signals to the engine control package. The action of all critical valves is indicated to the computer by mechanically actuated position switch readings. Specification values for valve action times are programmed into the computer, where comparison with actual times provides a "go/no-go" indication.

The indicated events to be monitored are those which now appear to be critical. Such events as bleed valve closure and purge valve opening and closing do not usually require monitoring after vehicle assembly. For those valve operations that are monitored, magnetic pickups (which do not make direct contact with moving valve elements) may be better suited to some valve designs than mechanically actuated position switches. Moreover, magnetic pickups are more reliable. The particular design used should be thoroughly evaluated for each specific application.

In the engine start sequences, the main stage start signal is generated by turbopump speed indicators. For sequence checks, simulation of the main-stage signal appears more desirable than actually operating the turbopump with an auxiliary device.

8.5 Propellant Loading Calibration

The loading concept previously discussed in connection with the C-1 and C-5 automation system design utilized delta pressure transducers for determining propellant levels in the vehicle tanks and facility storage tanks. The final loading operation utilized a partial delta pressure transducer for greater accuracy. The pressure sensors used can be given a final checkout and calibration by the method proposed in Section 8.2.1 immediately prior to the propellant loading operation. This calibration would provide the computer with the information necessary to control the final desired propellant levels with required accuracy.

Although liquid hydrogen loading experience is limited, comprehensive test programs have been conducted with liquid oxygen to determine accuracy capability of partial delta pressure transducers. Results have demonstrated that this method provides the desired accuracy and should be adaptable to use with liquid hydrogen.

Another way to determine final propellant levels is by point sensors. Although this method provides the desired accuracy, it requires additional complex ground equipment.

Although not specifically considered in previous discussions, it may be necessary to prechill the LH_2 tanks prior to initiating propellant loading with LN_2. Should such be the case, this additional operation as well as purging of the tanks could easily be accommodated by this concept.

Final checkout and calibration of propellant utilization systems, if they are used, could be accomplished during the propellant loading operation. Determination of the optimum method depends upon the type and design of the particular system that might be used.

9. SPECIAL STUDY AREAS

This section describes a number of major system areas which require additional study. These particular areas were identified and given initial thought during the preliminary study activity, so that the scope of the future work could be planned and described.

9.1 Common Digital Language

The definition of language and format is one of the most important and pervading system design activities for a digital system. The philosophy and choice of format strongly influence and interact with equipment specifications of the various subsystems, method of operation of the system and subsystems, complexity of conversion and buffering devices, programming philosophy, training of personnel, etc. In a system as complex as the Saturn space vehicle, which has multiple stages, many different contractors, different payloads and missions, various test sites, and multiple computer operations, it is essential that all of the stages as well as the spacecraft be designed in connection with their respective ground support equipment to utilize a common digital language and data format.

There are many advantages of a uniform language and format structure:

a) Operating personnel would be able to familiarize themselves with overall system operation more quickly if all communication within the system were in a common digital language.

b) Equipment compatibility problems would be minimized in that many of the design problems solved for one stage would be applicable to all stages.

c) Test integration of the vehicle from one site to another would be facilitated by use of a common design for much of the interface and data processing equipment.

d) The problem of systematically processing the large quantity of data obtained from the various test sites would be greatly reduced if all data were generated and recorded with a common format.

e) Standardization of test procedures and computer programs at the various test sites would be accomplished with more ease and success.

There are certain compromises implicit in a system design based on common language. Strong coordination between the various contractors and subsystem manufacturers becomes essential, and some wastefulness in digital storage efficiency is probably inevitable. Although the advantages outweigh the disadvantages, a careful study of this problem is needed to evaluate trade-off considerations and to arrive at an optimum solution.

The study of format and language will determine the total requirements for digital communication and data processing at all test sites and must identify any special system constraints imposed by existing equipment designs or facility characteristics. Among the constraints to be considered and the type of test data information to be defined are the following:

a) Characteristics and language of the onboard digital systems, including the guidance and control computer and the digital telemetry.

b) Characteristics of the ground computers; i.e., the use of the RCA 110 computer would dictate a format structure which is a suitable multiple or submultiple of 24 bits.

c) Characteristics of the various test parameters measured and method of their measurements, i.e., type of sensor, location of sensor, range of values, type of indication (amplitude, digital, pulse rate, frequency, etc.).

d) Purpose and usage of each test measurement, including identification of whether the measurement is operational or telemetry.

e) Site where each test is performed, such as factory, static firing, vehicle assembly, etc.

f) Reliability requirements on GSE error checking and redundancy, which depends on criticalness of the measurement and dependability of the equipment.

g) Nature and type of operator input and output data, i.e., formatting and coding needed to facilitate the man-machine communication and to simplify design of the various control and display consoles.

h) Format provisions needed to identify test signals, so that the automatic switching, communication, and processing equipment can handle the data in the desired operational fashion.

Consideration of the above and related factors will lead to a specification of a standard data format and identification system to be used throughout the Saturn program. Definition of this system at an early stage in the program is important to permit the progress of compatible design work on such items as control and display consoles, buffering equipment, computer programs, data link equipment, etc.

9.2 Apollo GSE Integration

The most complex final stage now planned for use with the Saturn vehicle is the Apollo spacecraft. Integration of this spacecraft into the vehicle system will impose significant technical problems not only for the flight system, but also for the ground support equipment. The task will be especially complicated because of the number of industrial contractors and divisions of NASA involved, but it can be assumed that all organizations will have the common goal of designing a system which will provide a rapid and smooth prelaunch preparation and countdown of the overall space vehicle. To facilitate this objective, the Apollo GSE should function in close cooperation with the Saturn vehicle automation system. Whatever GSE configuration is planned by North American Aviation under the direction of the Space Task Group, the details by which the Apollo GSE communicates and interfaces with the Saturn system should be given immediate attention to ensure development of an optimum approach and to facilitate the necessary design integration.

This effort will require close technical coordination and cooperation among the various companies and agencies involved. The first step should be formulation of an overall GSE integration concept, based on a desire to maximize reliability and to minimize hardware and interface complexities. Based on this overall concept, the second step would involve detailed technical studies to define the exact nature of the functional and electrical interface.

9.3 Optimum Utilization of Telemetry Data

One of the most important considerations in the design of the Saturn automation system is to make optimum use of vehicle measurement data while maintaining reasonable requirements on input/output equipment of the RCA 110 computer. The proper apportionment of hardline and telemetry measurement data, determination of data processing requirements, and selection of computer peripheral equipment are specific tasks associated with this general system area. Examples of the studies which need to be performed are:

a) Determination of which vehicle measurements should be hardlined, telemetered, or both.

   1) Which instrumentation (measurements) will and should be active during various phases of test?

   2) What are measurement frequency response requirements for checkout in various stages of test? (Some normally high frequency under flight are practically static during ground test and vice versa.)

   3) What ground test functions (measurements) are required that are not required during flight? What instrumentation equipment must be added to the vehicle for the "ground test only" type measurement? How does the weight penalty for this equipment compare to acquisition of the same information through the telemetry system?

   4) What instruments or functions require backup via landline during ground checkout? To what extent should the telemetry system be checked out via landline data comparison?

b) Determination of the most efficient form of telemetry data, where a choice of analog or digital data still exists.

   1) Which measurements are digital as measured? Which measurements are analog as measured?

   2) Which measurements must remain digital to maintain accuracy? Which measurements must remain analog to maintain precision? (e.g., high frequency type). Which could be converted to digital form to facilitate data processing?

   3) In what form will the data be used for direct evaluation during test and for systematic performance evaluation?

   4) Are the capacities of the digital and analog telemetry systems sufficient? Can they be increased? Can adaptive systems be used to reduce the redundant data being telemetered or used in the test and launch operation?

c) Determination of which telemetry data should be automatically evaluated by the computer.

   1) What point in time during the test and launch operation should the information be checked? Which functions require dyanmic measurement checkout? How much diagnostic decision-making will the computer do?

   2) What groups of data have static values and tolerances which can be predetermined and are indicative of system performance?

   3) What functions are event oriented? What functions have changes in static values after the event?

   4) Which functions must be compared to past time history performance?

   5) What information can be determined from several functions as an indication of success or failure of the test?

   6) What information is required that is not directly measured, but can be calculated from other measured functions?

d) Determination of optimum methods of processing analog telemetry data for insertion into the computer.

   1) What analog data must be fed to the computer during and after the test?

   2) What accuracy, sampling rates, and sampling period are required?

   3) What effect will noise on the channel have on the automatic evaluation? What filters are necessary?

   4) Are buffers required after analog-to-digital conversion of analog telemetry data? Are buffers required for the PCM data prior to insertion into the computer? What tape recording capacity is needed?

e) Determination of requirements for real-time monitoring, recording, and general display of telemetry data.

   1) What data is required at each monitor station? Can it be best presented in digital or analog form for decision purposes?

   2) What element of time is allowed for decision during the test?

   3) What level of technical competence is needed at each station?

4) Is it feasible to play back original data through the check-out system for post-mortem?

5) What data should be recorded on real-time visible records? What data must be recorded for general performance certification or for further or later evaluation?

6) What capability should be provided for troubleshooting operations in the event of a telemetry "no-go" from the computer?

Completion of these and related studies will assist with other detailed systems work aimed at generation of an overall measurement list, definition of overall data processing and computer input/output requirements, and definition of telemetry ground station requirements.

9.4 RIFT Stage GSE Integration

Some special considerations and requirements exist in the use of the reactor in-flight test (RIFT) stage in the Saturn program. These considerations include special handling, testing, control instrumentation, fueling, and safety techniques which are peculiar to the RIFT stage and which have varying impact on the facility and operational requirements at each assembly and test area. However, it appears that the general approach and equipment used to automate test and launch operations for the liquid propulsion stages can be completely compatible with electrical checkout requirements for the RIFT stage.

Work performed previously at STL in conjunction with a funded MSFC study on vehicle size and cost analysis* indicates that the use of a reactor with the Saturn vehicle has a much greater effect on mechanical handling and servicing requirements than on electrical checkout. However, electronic test equipment located in close proximity to the reactor may be required to operate and survive in some radiation environment. In addition, there are a few special test requirements, such as emergency shutdown provisions and related safety measures.

*Sohn, Robert, et al., "Launch Vehicle Size and Cost Analysis Phase I Summary," Space Technology Laboratories, Inc., 9862.2-41, 15 June 1961 (Confidential).

The study effort required for integration of the RIFT stage into the test and launch automation system is similar to that described in other sections for the liquid propulsion stages. The first effort should be aimed at defining detailed test requirements, including the type of measurements to be provided and the usage to be made of the test data. A similar effort should be aimed at determining the exact nature of safety provisions required both for local and remote operation of the reactor, such as continuous automatic monitoring, auxiliary manual controls, manual override, special display, etc. Although the development of this stage has not progressed as far as the liquid propulsion upper stages, preliminary studies in this area should be completed early so that the automation system can be developed with the necessary capability for integration of RIFT requirements and stage-interface GSE at a later date.

9.5 Data Link Requirements for C-5 Automation

The data link as presently invisioned was discussed above in Section 6.3.8. However, complete specification of requirements must await further definition of the philosophy to be used for operation of the two-computer system on launch day. In designing a multiple-computer system as used with the Saturn Complex 39, careful attention must be given to the relative roles of the computers to prevent the communication problems from becoming the limiting factors affecting system operation. This is especially true when the communication bandwidth is sharply limited, as in the present case. Fortunately, the Saturn application lends itself to a near optimum solution. With proper design, the transmission requirements can be greatly reduced by using the pad computer as a slave which accepts only control instructions from the central operational computer and transmits back only status and results. This approach also greatly reduces the data processing requirements for the central computer, since it is no longer required to handle details of the test operation.

The possibility of using the central computer for extensive processing of telemetry data is very attractive since performance information from this source should minimize the requirement for transmission of the same data over the hardline data link. As assumed for this study, this approach should provide test operators in the launch control room with adequate performance information while not placing undue requirements on information capacity of the data link. Whether this approach is feasible should be studied at length, with resulting conclusions based on a detailed definition of data which will be required at the launch control room to facilitate the test and launch operation. If it is found desirable or even necessary to transmit large amounts of detailed performance data over the ground link, consideration will have to be given to use of data links with greater bandwidth than anticipated or use of multiple links with lesser individual capacity. Trade-off studies related to this general problem should be initiated immediately with the objective of defining data link requirements as soon as possible.

9.6 System Simulation Studies

One of the most powerful tools available for development and evaluation of digital data processing equipment is that of interpretive routine simulation of the digital system operation. This type of simulation, coupled with combined analog and digital simulation of the other system elements, has been used extensively at STL to provide an investigative, diagnostic, and proof testing capability of the closed-loop missile guidance systems for Atlas, Titan, and Minuteman. This tool has been found to be especially valuable when used in conjunction with a hardware testing program. Properly used, it has the ability to ferret out logical errors in the system, prevent harmful equipment malfunctions, and provide a mechanism for detailed debugging of the entire system in advance of, and in parallel with, the hardware effort.

In addition to the verification of the logical design of the control, display, and communications equipment associated with the Saturn complex, a major use of simulation techniques would be in studying and establishing system program and procedures. Considering the extreme complexity of system operation with several consoles, multiple priority interrupts from many sources, multiple computers, as well as the problems involved in automating holds, recycle operations, and emergency aborts, it appears that an extensive simulation provides the quickest and least-expensive means of achieving effective system operation.

Experience has shown that a simulation of this type fills a need which is complementary to a system breadboard of the type planned by MSFC. A breadboard system is most valuable in working out the problems of physical integration, and in studying and debugging specific test sequences. On the other hand, an interpretive simulation is best applied to functional problems at the overall system level.

A simplified flow diagram of a typical simulation program for the automation system is shown in Figure 9-1. The simulation draws heavily on routines already in existence at STL and assumes use of an IBM 7090 computer. A general purpose program, which includes the effects of a synchronous operation between elements, either by design or as induced by human operator or external device, is also available and can be used to carry out the simulation.

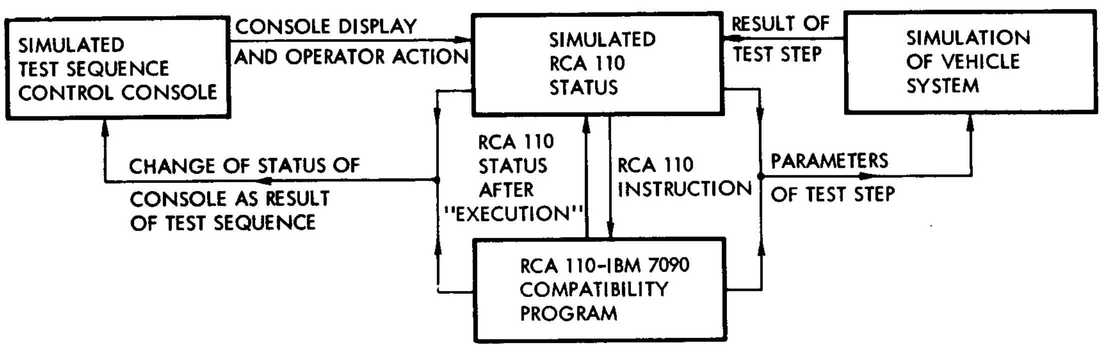

Figure 9-1. Simplified Simulation Plan

The control, display, data processing, and buffering equipment would be simulated on a pulse-by-pulse, gate, and flip-flop level. The RCA 110 is simulated, using a 110-7090 compatibility routine. This routine permits the running of RCA 110 programs on an IBM 7090. The simulation is not a logical simulation of the RCA 110, but rather a procedure where the 7090 picks up an instruction written in RCA 110 language, interprets its function, and "executes" the operation adjusting the contents of all registers, accumulators, and storage locations. Although the internal workings of the peripheral equipment do not require simulation in great detail, the communication between the RCA 110 and peripheral equipment is important and would be simulated rather thoroughly.

The vehicle itself need be represented only grossly except in the case of the guidance computer, where a detailed logical simulation of the Titan computer is already available and would be used.

In simulating one computer by another, a certain penalty is paid in the number of instructions needed. Past experience has shown that this penalty is in the range of 10-to-one to 50-to-one. However, the operating speed, advantage of the IBM 7090 over the RCA 110 is greater than the above ratios, allowing the simulation to proceed in real time if required. Real-time simulation provides the capability to use actual breadboard or portotype equipment, including consoles and displays. It is possible, therefore, to use a simulation setup for the design and evaluation of operator actions and for the training of operators.

There is sometimes a tendency to undertake a simulation effort without adequate definition of the precise results to be obtained. The detailed simulation program steps are not difficult to write, but exercising the program to achieve a desired objective is often another matter. Therefore, a preliminary study should be undertaken to define in detail the specific goals to be achieved, the method of exercising the program to achieve them, the overall program flow diagram, and the precise level to be simulated in each part of the program.

After set up and operating, the simulation should be used to facilitate a number of special design and evaluation studies. Included are the general class of studies aimed at evaluating the effects of various possible computer malfunctions which interrupt or distort information flow. Simulationprograms available permit the arbitrary insertion of malfunction conditions. It is possible to specify a single faulty action of a component, a period of time during which an operation remains faulty, or a permanent fault. The program can print out step-by-step or selected results for examination by the designers of the equipment and the procedures. The effects to be studied or evaluated include inavertent launch of the vehicle, failure to detect a vehicle malfunction, erroneous vehicle fault indication, loss of control during critical test or launch operations, etc. Another general class of studies involves evaluation of individual test sequences and provision for fail-safe combination of these stored sequences into longer test programs by the computer operator.

9.7 Mechanical Test Operations

Automation of the mechanical operations are, to a large extent, dependent upon the detailed design of both the vehicle and facility. Two areas requiring a major effort for system optimization are propellant loading and leak testing.

In order to accomplish propellant loading in a safe, accurate, and expeditious manner, considerable study effort needs to be accomplished. Reliability of the system and its components must be the keynote of the system design. Selection of the types of sensors as well as their locations must be made so that a computer will have the necessary flow of information which it requires for an automated operation. Facility instrumentation to provide status and performance data is equally as important as vehicle instrumentation.

The loading of liquid hydrogen into large stages has not, as yet, been accomplished as part of a launch operation. While it is anticipated that the operation may be quite similar to the handling of liquid oxygen, problems peculiar to this liquid may arise particularly in the area of propellant tank chilldown, boiloff, and sensor activation.

The propellant loading system previously discussed was predicated upon utilizing a delta pressure sensor system. It may be that a system employing point sensor probes will have to be used to provide greater accuracy for final liquid level determination. This type of system would require additional ground circuitry of a complex nature for sensor excitation and information extraction. It also would require location of sensors inside the vehicle tanks, thereby making replacement of faulty sensors difficult if not impractical. Additional trade-off studies involving both accuracy and automation considerations are urgently required before either the point sensor or delta pressure approach is finally selected for propellant loading.

Auxiliary pumps may be required on the transporter-launcher to provide the necessary flow rates to the upper stages. Subcoolers also may be required to provide the proper liquid temperatures so that excessive boiloff will not occur during the loading operations. These additional considerations further emphasize that successful development of an automated propellant loading system is a complex task requiring careful consideration of the many trade-offs which affect the vehicle and facilities as much as the automation equipment itself.

Leak testing is so interdependent with the detailed design of the vehicle that a determination of the requirements must be assessed on a continuous basis as the design progresses. A common approach needs to be implemented so that the various contractors can incorporate the necessary provisions for automating leak checks as the stage designs proceed. The plumbing associated with the propulsion systems, pneumatic systems, and propellant loading and feed systems must be analyzed for leakage areas of critical importance. Studies based upon the preliminary stage designs, propulsion system designs, and the operational concept for the vehicle will indicate the requirements for leak testing, and can be used for development of an automation approach.

9.8 Test Data Processing

An important factor to be considered in the overall system design is the division of responsibility between the computational element of the automation system and external computational facilities for processing and evaluation of test data. It is assumed that all test data will be recorded and that external computational facilities will be used for systematic evaluation of at least portions of the data. The records of all test (as well as operational) data are properly cataloged and stored for later use. In other space programs, it has been found that recordings, which at the time did not seem necessary for the contemplated evaluations, were often used subsequently for such purposes as comparisons with later runs, more detailed analysis of equipment functioning or malfunctioning, development of reliability data, etc.

A general plan for use of an external data processing system should be developed as early as possible to facilitate definition of complementary and compatible requirements for the automation equipment. This plan should include a definition of the test data to be evaluated on a systematic basis, requirements for data format, methods of data recording, etc. The studies of data language, use of telemetry data, and system simulation discussed in other parts of this general section are intimately related to this data processing study and represent additional factors which should be considered.

9.9 Analyst Display Requirements

The analyst displays as described in Section 6.3.3 for the fully automatic C-4 system represent a logical carry-over from the manual operating positions used with the C-1 complex. The purpose of these displays is to provide a trained specialist with sufficient information to intelligently monitor performance of his subsystem or stage without impeding progress of the test during normal operation. Proper design of the analyst consoles can be the most important factor leading to successful and effective use of the automation system.

A delicate balance will exist in providing the proper type and amounts of test information. Too little information will minimize the effectiveness of the test analyst, while too much can impose a large computer programming burden, slow down the test operation, and possibly lead to an overly dominant role for the analyst. A detailed study should be initiated to define requirements of the following nature:

a) Determine test functions and information to be displayed

b) Identify the exact number and type of consoles required

c) Determine the source of information to be displayed, i.e., operational or telemetry measurements.

d) Determine the data processing requirements and signal interface with the RCA 110

e) Determine the method of displaying each test parameter

f) Develop a concept for use of the analyst console both during normal test and launch operations and during special troubleshooting operations.

It might be necessary to perform some experiments in deciding upon the appropriate methods of presentations and controls. Such experiments can be performed, to a certain extent, with mockups of the console and, to a much greater and more detailed extent, with breadboard equipment connected to a simulated system. System simulation, as described in Section 9.6, could be readily augmented to include the evaluation of human factors in the information processing loops. The need and extent of such studies should be determined at an early stage in the automation system development program.

9.10 Checkout in Orbit

A general description of the guidance computer interface with the automation system has been presented in a previous section. For various rendezvous missions, it is anticipated that the guidance computer will be required to perform an independent checkout of the S4D stage while in orbit. This problem is similar to one studied extensively by STL during their recent Apollo proposal where investigations were made into an on-board maintenance device which worked in conjunction with the telemetry system to provide a checkout capability during space flight. For the Saturn application, it will be necessary to verify proper performance of the checkout operation on the ground prior to launch and to record data for later comparison with in-flight test measurements. It is anticipated that much of the in-flight test operation will consist of direct "go/no-go" evaluation by the on-board computer, with results relayed to the ground. Supplementing this on-board testing will be independent evaluation of telemetry data on the ground. Further definition of the test operation will require much additional study, with initial emphasis placed on the following general areas:

a) Determination of the individual measurements required

b) Investigation of the capability of the guidance computer to independently perform the required in-flight measurements

c) Investigation of the method by which the test operation should be verified prior to liftoff

d) Development of a procedure which provides adequate checkout of the orbiting vehicle and assurance on the ground that the checkout has been performed satisfactorily

e) Definition of the control and signal flow interface between the ground and airborne computers both prior to and after launch.

APPENDIX A

SUMMARY DESCRIPTION OF SATURN C-1 AND C-5 VEHICLE SYSTEMS

INTRODUCTION

The goal of the Saturn C-1 program is to inject unmanned and manned capsules into low earth orbit. The major objective of the Saturn C-5 program is space exploration, including manned circumlunar navigation (Apollo), lunar surface exploration (Prospector), and interplanetary missions (Voyager).

THE C-1 PROGRAM

The C-1 program will progress through several evolutionary phases during which the individual stages and major system will be developed and tested in readiness for the final flight vehicle.

There are two major blocks of vehicles in the C-1 program.

Block I Vehicles

Block I includes the first four vehicles, SA-1 through SA-4. This configuration (Figure A-1) consists of an S-1 stage manufactured by MSFC, a dummy S-IV stage, a dummy S-V stage, and a dummy payload. (The payload comprises a Jupiter nose cone and adapter.) Study of control, environment, tracking, telemetry, and large vehicle launch control problems will be accomplished by flight tests during 1962 and 1963.

The S-1 stage incorporates eight Rocketdyne H-1, Phase I engines using liquid oxygen and RP-1. Each engine is rated at 168, 000 pounds of thrust. The outer four engines are gimballed. However, because control torque is limited, the S-V stage must be heavily ballasted.

The electronic equipment consists of telemetry, guidance and control, and tracking equipment, and will be located in the adapter area on top of the S-I stage.

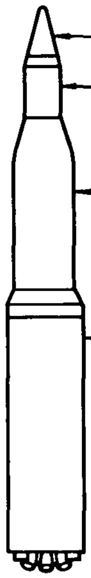

Figure A-1. Saturn C-1 Vehicle, Block I

A typical telemetry system for vehicles SA-1 through SA-4 is as follows:

Telemetry Link No. 1

PAM/FM-FM
216 channels sampled at 12/second
14 continuous channels

Telemetry Link Nos. 2, 3, 4, and 5

PAM/FM-FM-FM
54 channels sampled at 10/second
8 channels (flowrates) sampled at 1/second
13 continuous channels FM-FM
8 continuous channels FM-FM-FM

Telemetry Link No. 6

PAM/FM-FM
54 channels sampled at 10/second
15 continuous channels FM-FM

Telemetry Link Nos. 7 and 8

SS/FM
15 continuous channels for vibration data, 50-3000 cps

Vehicle SA-3 will carry the following developmental hardware:

a) One FM-FM system in the 2200-Mc band, with redundant transmission of data telemetered by T/M No. 6.

b) One PCM (pulse code modulated) - FM link in the 225-Mc band duplicating transmission of data from T/M No. 1.

The guidance and tracking systems are similar to those in the Block II vehicles and will be described later.

Block II Vehicles

Block II includes vehicles SA-5 through SA-10. This configuration (Figure A-2) consists of an S-I stage manufactured by MSFC, an S-IV stage manufactured by Douglas, and an instrumentation section and payload. These six vehicles will be launched from mid-1963 to mid-1964 to test S-I/S-IV staging, S-IV operating capabilities, and guidance and control through S-IV cutoff. Payloads for SA-5 and SA-6 will be Jupiter nose cones and aft sections. SA-7 through SA-10 will use Apollo "boilerplate" capsules.

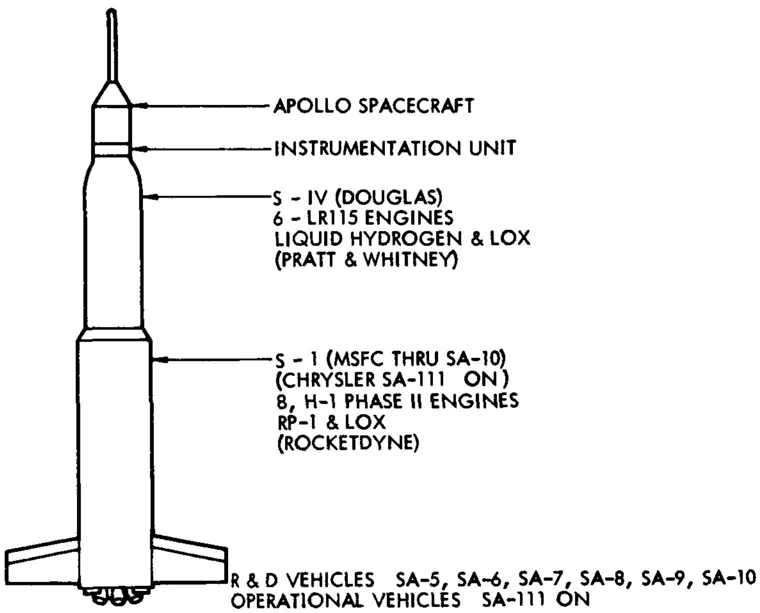

Figure A-2. Saturn C-1 Vehicle, Block II

The Block II, S-I stage uses eight Rocketdyne H-1, Phase II engines of 188,000 pounds thrust each. The engines feature increased control torque to accommodate the S-IV stage.

S-I telemetry for a typical Block II vehicle is shown below:

a) Two each, type X06-C, PAM/FM/FM
   216 channels PAM/FM/FM, sampling rate 12/second, frequency response 2.5 cps
   13 channels FM/FM
   These telemeters primarily transmit measurements of temperature, pressure, fuel level, etc.

b) One each, type X06-D, PAM/FM/FM
   27 channels PAM/FM/FM, sampling rate 120/second, frequency response 25 cps
   13 channels FM/FM
   This telemeter is used primarily for bending accelerations in main body and fins.

c) One each, type X06-E, PAM/FM/FM
   54 channels PAM/FM/FM, sampling rate 120/second, frequency response 25 cps, time-shared 3 seconds each, in groups of 27.
   13 FM/FM channels
   This telemeter is used primarily for strain gage measurements in fins 1 and 2.

d) Two each, type X07, SS/FM
   15 channels, frequency response 3 kc
   Time-sharing techniques will be applied to 19 of these channels to cover requested measurements. These telemeters are used for vibration and sound measurements.

The telemetry frequencies are 242, 246.3, 249.9, 253.8, and 259.7 Mc.

One PCM (pulse code modulated)/FM link in the 225-Mc band duplicates transmission of data from T/M No. 1.

The only other r-f link on the S-I stage is the range safety command destruct link.

External antennas for all links fasten to four panels. Each panel fits across two tanks, above each fin.

The second stage (S-IV) includes six gimballed, 15,000-pound-thrust, Pratt and Whitney engines, using liquid hydrogen and liquid oxygen. Ullage and retrorockets are Thiokol M-60, MOD I solid propellant type.

Telemetry

The telemetry system for the S-IV stage consists of three PDM/FM/FM telemeters, as listed below. (In-flight voltage calibration is provided on all FM channels.)

a) Two each PDM/FM/FM
   135 channels PDM/FM/FM, sampling rate 10/second, frequency response 2 cps
   8 channels FM/FM
   These telemeters are used primarily for measurements of temperature, pressure, voltage, etc.

b) One each PDM/FM/FM
   45 channels PDM/FM/FM, sampling rate 2.5/second, frequency response 0.5 cps
   9 channels FM/FM
   This telemeter is used primarily for measurements of temperature, vibration, pressure, etc.

The instrumentation section consists of the following equipment:

Time Base Selector

Program Device "J" Mod "O"

Networks

Platform distributor
Propulsion distributor
Heater Power distributor
Measuring distributors
Junction boxes
Power distributors
Main distributors
EBW firing unit
Control distributor
Switch
Abort distributor
Power supplies
750 volt-ampere inverter and regulator
Battery assemblies
Measuring voltage supply, 5 volts
Control voltage supply, 60 volts
Battery shunt box assembly
Flight sequencer

Instrumentation and Measuring

UDOP transponder set
UDOP r-f amplifier
Radar altimeter
Azusa
C-band radar
Telemeter X0-4
Telemeter 216 channel
Telemeter SSF M
Telemeter PCM
Command receiver and decoder
Command receiver power supply

Special Equipment

Continuous light assembly
Horizon sensor
Horizon sensor power supply

Air Bearing System

Air bottle
Air bearing regulator No. 1 and Heater
Heater thermostat assembly

The all-inertial Saturn guidance and control system uses a digital computer for the guidance computations and an analog computer for the control functions. Acceleration measurement for the guidance system and accurate attitude angle measurements for the control system are obtained from the stabilized platform subsystem.

The guidance and control system operates in two modes, which are functionally and mechanically interrelated. The control mode takes account of the basic stability requirements of the vehicle and provides proper control torques to overcome any disturbance of the vehicle's attitude from a desired reference. The guidance mode determines the trajectory for attaining the correct velocity vector, space coordinates, and time of arrival at destination. Many practical and desirable considerations are also accommodated in the guidance mode, such as minimizing propellant usage for a given mission to permit a larger spacecraft.

All inputs to the guidance and control modes are obtained primarily from the stabilized platform of the all-inertial system. The three mutually perpendicular accelerometers of the platform supply data for the guidance mode and highly accurate reference attitude information (in pitch, yaw, and roll) for stabilization of the vehicle in the control mode. Control accelerometer outputs are combined with the attitude information to limit excessive buildup of vehicle angle-of-attack during critical periods of flight. Rate gyros and differentiating networks provide attitude rate signals. Complex shaping networks, based on the total stability requirements, are included in the control computer.

Computations involving guidance and control signals are accomplished in a general-purpose digital computer and analog computer, respectively. Initially, a 3000-word digital guidance computer will be used for flight computations and portions of the prelaunch checkout. For later vehicles a digital computer, incorporating advanced technology and reliability approaches and a larger and expansible memory, will be provided.

The guidance system also includes a launch computer which is tied to the vehicle's computer and platform. This arrangement allows a continuous change of flight program constants and platform aiming azimuth.

Combined with the allowable launch window variations afforded by the adaptive guidance mode, this hardware capability will be adequate for any foreseeable injection requirements.

The analog control computer uses a combination of magnetic amplifiers and transistor amplifiers for summation, and an electromechanical device for programming gain changes. Studies are underway to determine the feasibility and necessity of applying the digital computer to both guidance and control functions in later Saturn configurations.

The guidance and control system also computes or provides signals (e.g., staging, cutoff, etc.) to the propulsion system and the overall vehicle.

A typical telemetry system for SA-5 and subsequent vehicles is listed below:

a) One each PCM/FM
PCM channels for digital data from guidance computer, etc.
40 channels PCM, sampling rate 12/second, frequency response 2.5 cps
9 channels SS/FM
This telemeter is used primarily for guidance, vibration, and temperature measurements.

b) Two each type X0-4, PAM/FM/FM
15 channels FM/FM
12 channels FM/FM/FM
These telemeters are used primarily for guidance and control measurements from both live stages.

The telemetry equipment, located in the instrument unit, consists of three FM/FM sets and one PCM/FM/FM set. This telemetry system then has 48 standard IRIG analog channels and a PCM bit rate of 36, 000 per second.

All of the r-f links for tracking are carried in the instrument compartment. This includes the UDOP, Azusa, radar altimeter, C-band radar, and a developmental tracking system now in the design stage.

The UDOP link is a uhf doppler tracking system that consists of a ground CW transmitter, a vehicle-borne transponder, and several ground receivers. The transponder receives the transmitted wave, doubles its frequency and transmits it. The ground-based receivers are located near the launching site at points geometrically spaced for best results. The receivers receive both the basic wave and the doubled wave, and compare the relative frequencies. Information from three receivers is sufficient to locate a vehicle in space.

The Azusa system is similar to the UDOP system except that the Azusa transmitter sends a modulated wave. Also, the Azusa transponder does not double the frequency, but shifts the carrier several megacycles away from that originally transmitted. The modulation is used for fine measurements in the doppler system.

The C-band radar is a standard-pulse-type radar operating at 5555 Mc/sec and using a high-gain parabolic antenna on the ground and a repeater-type transponder in the vehicle.

The antennas are all of the external configuration and are located on the skin of the instrument compartment.

The frequencies are:

Telemetry	248.6 Mc 252.4 Mc	256.2 Mc 1 unassigned
UDOP	900 Mc and 450 Mc	
Azusa	500 Mc	
Radar altimeter	Unassigned	
C-band radar	5555 Mc	
Development tracking	Unassigned	

The command destruct system is an improved Jupiter system consisting of separate command destruct receivers in each stage interconnected to the destruct systems in both stages. A command destruct signal will cause an automatic abort signal to be sent to the spacecraft.

Upon completion of the development vehicles (SA-1 through SA-10), the operational vehicles (SA-111 and subsequent) will be launched through FY 1966. The major difference in these vehicles will be the manufacture of the first stage (S-I) by Chrysler Corporation and the new missions, which will include manned earth orbit (Apollo).

The Saturn C-1 vehicles SA-1 through SA-4 will be launched from a single launch pad at AMR complex LC34. The remainder of the C-1 vehicles will be launched from dual launch pads at complex LC37.

THE C-5 PROGRAM

The basic three-stage vehicle (Figure A-3) includes a Boeing S-IB stage powered by five Rocketdyne F-1 engines using RP-1 and liquid oxygen.

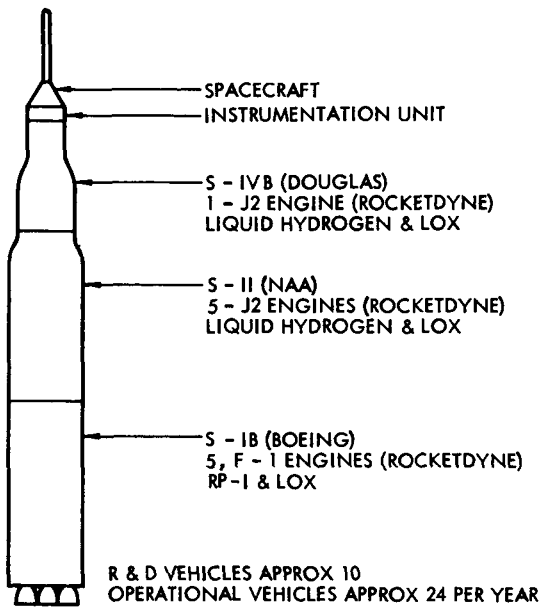

Figure A-3. Saturn C-5 Vehicle

The second stage (S-II), manufactured by North American, is powered by five Rocketdyne J-2 engines developing 200, 000 pounds of thrust each. Propellants are liquid hydrogen and liquid oxygen. These engines have multiple restart capability.

The third stage is an S-IVB, manufactured by Douglas and powered by one J-2 Rocketdyne engine as used on the S-II stage. Restart capability will also be required on this stage.

The instrumentation section, including guidance and control and telemetry, will be similar to the equipment used for the Block II, C-1 vehicles. Automatic checkout equipment will be required for all stage checkout and vehicle checkout and launch. A digital data link will be used between the vehicle at the launch site and launch control. The checkout equipment must reflect the more stringent requirements of manned missions.

The overall research and development programs scheduled from FY 1962 through FY 1967 with approximately 10 vehicles the first 2 years and 12 per year thereafter. The operational program will be approximately 24 vehicles per year.

Vehicle launches will be from VLF-39 at AMR, using two launch pads and vertical assembly of four vehicles at one time. Total vehicle assembly, checkout, and launch time is approximately nine weeks.

SATURN VEHICLE CONTRACTOR SUMMARY

Stage S-I	Chrysler Corporation
Stage S-IB	Boeing Aircraft Company
Stage S-II	North American Aviation
Stage S-IV	Douglas Aircraft Company
Stage S-IVB	Douglas Aircraft Company